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Special Issue: The Next Steps in International Safeguards

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Special Issue: The Next Steps in International Safeguards

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INMM
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Challenges We Face in the Future

By Steve Oritz
INMM President

During the past month I have been exposed to two papers that relate to the future of nuclear materials management. Jack Jekowski gave his update at the Southwest Chapter's spring meeting in Taos, New Mexico, USA, on "Complex Transformation and the Future of the U.S. Nuclear Security Enterprise," and Olli Heinonen wrote a paper titled, "20/20 Vision: Future International Safeguards" Both these papers describe a changing environment for nuclear materials.

Jekowski's paper basically deals with the restructuring on the U.S. nuclear weapons complex. He has presented a paper on this topic the last four years at the Southwest's Chapter's spring meeting, each year giving his view of the current status. This year he discussed the new era in White House foreign policy. The new U.S. administration is focused on eliminating nuclear weapons. He cites several instances where President Obama has spoken about reducing and eventually eliminating existing nuclear arsenals. This will only make nuclear material management even more important. It could have an impact on how we store, process, manage, transport, secure, and manage the waste from nuclear material.

Heinonen's paper addresses the International Atomic Energy Agency's (IAEA) 20/20 Report of the Commission of Eminent Persons on the Future of the IAEA. He cites the tremendous increase worldwide in the use of nuclear energy and nuclear technology. Even though these are peaceful uses of nuclear material, we all realize they also present more proliferation opportunities. Heinonen's paper addresses the impact this is having on the IAEA. What is also very clear from his paper is the need for more nuclear materials managers to work in this growing industry. Many countries seeking nuclear energy and technologies have no prior experience with nuclear materials.

I recommend reading both of these papers. One addresses the restructuring of the U.S. nuclear weapons complex and the other addresses the worldwide growth of the use of nuclear energy and technologies. They both identify opportunities for growth in nuclear materials management.

It doesn't matter if nuclear materials are being used for weapons or peaceful means. The management of these materials is critical for the safety and security of all of us. Our challenge is to continue to develop methods and technologies to ensure that nuclear materials are managed in the safest and most secure way. Nuclear energy and nuclear technologies are becoming more important to the population around the world. As nuclear materials managers it is our responsibility to be at the front of this growth.

INMM President Steve Ortiz may be reached via e-mail at sortiz@sandia.gov.

Excellent Papers on the Future of International Safeguards

By Dennis Mangan
Technical Editor

The theme of issue is the Next Steps in International Safeguards. Jim Larrimore, chair of the International Safeguards Technical Division, is to be thanked and applauded for spearheading the effort to get the fourteen papers in this issue on the theme, including a *Foreword* by Olli Heinonen, Deputy Director General of the International Atomic Energy Agency and Head of the Department of Safeguards. Larrimore even provided one of the papers, *Safeguards Technical Parameters: Directions for Evolution,* which I found to be very interesting. The papers address a broad spectrum of topics, including: the "3S-based system and infrastructure" focusing on the badly needed integration of safety, security, and safeguards; an update on the state-level approach to international safeguards, and discussions of the implementation of the approach; several papers on the challenges of the growing use of open source information and satellite imagery; a discussion on future technologies envisioned; a paper on the U.S. Department of Energy's National Nuclear Security Administration's Next Generation Safeguards Initiative; a discussion on improving the safeguardability of nuclear facilities through the application of "safeguards-by-design;" a paper on the Russian Federation's effort to move toward multilateral mechanisms for the nuclear fuel cycle; and finally a paper on verification challenges for those often forgotten efforts like the Comprehensive Nuclear Test Ban Treaty, and the Fissile Material Cut-off Treaty. All of these papers provide valuable information and insights on the future of international safeguards, and all are worth reading. Again, our appreciation and thanks to Larrimore for arranging for these papers. I trust you will enjoy reading these papers.

In March 2009, the Standing Committee on International Security of Radioactive and Nuclear Materials of INMM's Nonproliferation and Arms Control Technical Division sponsored a workshop in Santa Fe, New Mexico USA, *Reducing the Risk from Nuclear and Radioactive Materials.* As part of the workshop, a student paper competition was held. The winning paper, "When is Noncompliance, Noncompliance?" is included in this issue. It was presented by Karen Miller of the Nuclear Security Science and Policy Institute of Texas A&M University, College Station, Texas USA, where Miller is a doctorate candidate.

In this issue also is an In Memoriam for Vince DeVito, the Institute's long-time secretary. INMM was Vince's second family. He will be dearly missed. In preparing the In Memoriam, we violated our editorial rule that a person's full name is given the first time the name is use, but there after only the last name is used (typical of most newspapers). But that seemed inappropriate for someone with whom so many of us have known so well and for so long.

Should you have any questions or comments please feel free to contact me.

JNMM *Technical Editor Dennis Mangan can be reached by e-mail at dennis-mangan@comcast.net*

20/20 Vision: Future International Safeguards

The topic of this special section of the *Journal* will also be the focus of Olli Heinonen's Opening Plenary address of the same name at the INMM 50th Annual Meeting.

Olli Heinonen
International Atomic Energy Agency, Deputy Director General and Head of the Department of Safeguards, Vienna, Austria

Since 1957 the International Atomic Energy Agency (IAEA) has worked to bring the benefits of nuclear technology to humankind, while at the same time minimizing its risks. Over the last fifty years the world has seen a steady growth in the application of nuclear technology that now spans from the generation of electricity to applications in food security, resource conservation, environmental protection, human health, and more. We have also witnessed nuclear accidents, threats to the peaceful use of nuclear technology, and the emergence of clandestine nuclear procurement networks. Throughout this time the role of the IAEA has been, and remains, a fundamental component of the nuclear nonproliferation regime. The IAEA, and safeguards, have advanced tremendously and must continue to do so in order to address future changes and challenges. Although it might not be possible to predict them all with full certainty, there are some that can indeed be anticipated.

The 20/20 report of the Commission of Eminent Persons[1] on the future of the IAEA encapsulates the anticipated challenges and opportunities that the IAEA will face in maintaining global nuclear order. Trend projections for the coming decades indicate considerable growth in the use of nuclear energy and nuclear technology: the acquisition and utilization of nuclear technology is seen as a matter of economic, scientific, and technological advancement. While such benefits will bring greater prosperity to different parts of the world, it may also increase proliferation risks; without appropriate control measures, nuclear material and technology could be misused to build nuclear weapons.

Recently published IAEA studies show that nuclear electricity generation may grow by 17–45 percent by 2020 and by 27–100 percent by 2030.[2] To date nuclear power has been used mainly in industrialized countries. However, much of the future growth is expected to take place in the developing world: about half of the forty-four new reactors currently under construction are in developing countries, particularly in Asia. We also know that many of the new nuclear facilities to be established will be in states that have limited or sometimes no previous nuclear experience. Many of these states have also yet to establish or enhance their nuclear regulatory bodies and appropriate legislation and resources for effective state systems of accounting for and control of nuclear material.

Of the countries that already use nuclear technology for electricity generation, more have shown interest in mastering the nuclear fuel cycle to ensure a supply of reactor fuel for their nuclear power plants—a step that brings them closer to developing a nuclear weapons capability.

We have all witnessed the emergence of illicit nuclear technology trade in covert nuclear trade networks, whose activities span the globe. Such networks conceal their clandestine shipments within legitimate trade, often taking advantage of weaknesses of states' export control systems. The IAEA was disturbed to learn that sensitive information provided by the clandestine nuclear supply network existed in electronic form adding another dimension of challenge to nonproliferation.

How can the IAEA meet expectations in the changing environment? Through innovation and adaptation. New thinking is required to provide the IAEA's safeguards system with the *legal authority, technical capabilities, and financial and human resources* for it to be fit for tomorrow's environment.

With a changing landscape of increased nuclear proliferation challenges, and cases where the letter and spirit of the Nuclear Nonproliferation Treaty (NPT) has been threatened, a strengthened system of safeguards has been instituted that incorporates the additional protocol as well as state-level approaches to safeguards and a move towards information-driven safeguards. The IAEA can also be part of a solution to a multinational approach (MNA) to the nuclear fuel cycle that addresses the issue of proliferation of the sensitive aspects of the nuclear fuel cycle.

The IAEA's task of carrying out responsible safeguards verification to ensure the peaceful use of nuclear energy entails that timely and early detection in verifying states' compliance with their safeguards obligations is necessary. To carry out its verification activities effectively, the IAEA needs to have adequate inspection authority and access to all relevant information and locations. The IAEA's two main types of legal instruments are comprehensive safeguards agreements (CSAs) and additional protocols (APs). Together, the two instruments enable the IAEA to conclude that states are not diverting nuclear material to nuclear weapons.

Yet today, twenty-seven NPT state parties have not brought into force their required CSAs and some 100 states have yet to conclude an AP. The CSA-AP combination should, in my view, be the universally accepted verification standard, if verification is to be credible. It will also be important for the IAEA to fully utilize all measures available under these legal instruments.

This new standard would not only

increase transparency, but would also enable the IAEA to optimize its verification activities, resulting in a reduced inspector presence and workload in the states. Realizing such efficiencies will be increasingly important, especially in light of the projected expansion in the use of nuclear energy. The IAEA estimates an increase from the current 250 facilities to 350 facilities subject to actual safeguards by 2020, and eventually to 420 by 2030. However, despite the expected doubling of the number of facilities subject to safeguards, the estimated overall in-field efforts by 2030 is an increase of some 10 percent from the current level. If states give the IAEA the necessary legal authority—under both a CSA and an AP—efficiencies can be realised so that the IAEA can conclude and continuously reaffirm with a high level of confidence that they are not diverting nuclear material and have no undeclared nuclear material and activities.

In addition to the universalization of CSAs and APs the IAEA will need to move with the times when it comes to its technical capabilities. Having state-of-the-art verification technology will remain an important requirement, particularly for the detection of clandestine nuclear activities. The IAEA would benefit greatly from having the capacity to commission R&D in safeguards technology, be it in cooperation with member states or the commercial market. It will need to strengthen existing detection capabilities, especially with regard to environmental sampling, satellite imagery and information analysis. For example, the increasing number of environmental samples taken will require the IAEA to improve its own laboratory capabilities as well as to expand its network of analytical laboratories in member states. In addition, new types of nuclear reactors and associated nuclear fuel cycle technologies will emerge, requiring the IAEA to begin designing dedicated safeguards approaches and techniques well in advance. The IAEA will also work with states and facility providers and operators to design and operate "safeguards friendly" nuclear installations to facilitate efficient and effective verification.

The IAEA will continue to strive to finance its verification activities under the double challenge of increasing workload and member state pressure not to grow its budget but to seek efficiencies. Unpredictable, pressing verification responsibilities as well as the need to maintain verification infrastructure and equipment add to the IAEA's financial strain.

Regarding human resources, the IAEA will be facing the retirement of large numbers of experienced inspectors and senior staff in the coming years at a time when interest in nuclear energy, and therefore the needs for nuclear professionals, is growing. Yet, the global pool of experienced personnel with appropriate technical backgrounds has been shrinking in recent years. The IAEA will need to compete with industry and member states for experienced professionals. Its personnel policies will further compound that challenge. The retirement boom and personnel policies pose a challenge also to retaining and passing on critical knowledge to incoming staff.

In the future, the IAEA may also be called on to take on new roles, such as verification of nuclear materials released from military programs, thereby contributing not only to nonproliferation but also to disarmament.

New technology, sufficient financial and human resources, expanded legal authority and the demonstration of full commitment, cooperation and transparency from member states are not only crucial to the IAEA's verification role, but will also improve its effectiveness and efficiency. As we stand looking towards the future, now is the time for member states and the international community to make a difference. A resilient safeguards verification system that provides the necessary assurances is the ultimate stamp of confidence that promotes the peaceful uses of nuclear energy.

Notes

1. 2008. *Reinforcing the Global Nuclear Order for Peace and Prosperity: The Role of the IAEA to 2020 and Beyond,* Report prepared by an independent Commission at the request of the Director General of the IAEA.
2. 2009. *"Nuclear Technology Review 2009: Report by the Director General,* IAEA, GOV/2009/3.

The New Nexus, 3Ss: Safeguards, Safety, Security, and 3S-Based Infrastructure Development for the Peaceful Uses of Nuclear Energy

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Note: The views expressed in this paper are solely of the authors.

Abstract

Recently there have been worldwide phenomena of "nuclear renaissance," a global trend in expansion of or embarking on nuclear power generation, in view of attaining sustainable development, assuring energy security, and reducing CO_2 emissions. However, another major accident would ruin this nuclear renaissance and, therefore, there are governance implications worldwide. The introduction of nuclear power requires careful planning and implementation with a sustainable infrastructure to ensure that nuclear energy is used in a safe and secure manner, without diversion, throughout all the stages of its life cycle. The importance of safeguards, nuclear safety, and nuclear security, or "3S" is also fully noted in the Leaders Declaration at 2008 G8 Hokkaido Toyako Summit and the International Atomic Energy Agency (IAEA) has been promoting the 3S concept, recognizing the important interface among them and trying to maximize their synergy effects. Against this background, an international initiative proposed by Japan on 3S-based nuclear energy infrastructure has been launched. Based on its good record and substantial experience in 3Ss, Japan has been assisting developing and other countries in establishing the required infrastructure to assure 3S. This paper summarizes the efforts in this area and describes the future prospect.

Introduction

For the sake of meeting growing energy needs for sustainable development while assuring energy security and alleviating CO_2 emissions, there is a global trend to expand or embark on the use of nuclear energy for electric power generation in the coming years. This trend is often referred to as "nuclear renaissance." This trend is particularly strong in the Asia Pacific region.[1] The following countries in this region have extensive programs to expand or embark on their nuclear power program.

- China plans to expand its nuclear generation capacity from 8.6GW to 40GW by 2020 and 160GW by 2030;
- India plans to increase its nuclear generating capacity to 40GWe in 2020 and 60GWe in 2030 from only 4.1GWe today;
- Republic of Korea (ROK) currently has twenty nuclear power plants (NPP) with a total capacity of 16.8GWe in operation, and ten more plants are planned to be on the grid by 2030, increasing its nuclear generating capacity to 30GWe in total to cover 41 percent of electric generation capacity;
- Japan's fifty-three NPPs (47.9GW) are in operation, three NPPs (3.67GW) are under construction, and ten NPPs (13.6GW) are planned. Japan Atomic Energy Commission established a long-term nuclear energy policy in 2005, stating *"Therefore, it is appropriate to aim at maintaining or increasing the current level of nuclear power generation (30 percent to 40 percent of the total electricity generation) even after 2030."*
- Indonesia plans to commission its first 1,000MW unit in 2016 and expand its nuclear generating capacity to 4,000MW by 2025;
- Vietnam plans to construct NPPs with total capacity of 2,000 to 4,000 MW between 2017 and 2020; and
- Thailand plans to construct NPPs with 4,000 MW capacity in total between 2012 and 2021.

However, the cliché, "an accident somewhere is an accident anywhere," implies that another Three Mile Island or Chernobyl accident would ruin nuclear renaissance. In order to assure the general public's confidence on nuclear power generation, the issue of nuclear safety should be properly addressed to protect people and the environment from the harmful effects of ionizing radiation during normal operation and in the event of an accident. In addition to commitment to nuclear safety, it is mandatory to pay strict attention to the control of nuclear material. In preventing the use of nuclear power for the purpose other than civil use, measures for nonproliferation, especially those of safeguards, should be properly applied, assuring that all of the activities in a country can demonstrate that there is no risk of proliferation of nuclear weapons and that all the materials are adequately accounted for. Further, it must be assured that nuclear materials at a nuclear facility or in transportation should be securely protected lest it should fall into the wrong hands such as terrorists. Namely, nuclear security should be ensured. Thus, there are global governance implications of nuclear renaissance worldwide.

Importance of 3Ss and Synergies

Importance of 3Ss

As already mentioned, introduction of nuclear power requires careful planning, preparation, and implementation with a sustainable infrastructure and sufficient resources providing necessary legal, regulatory, organizational, technical, human, and industrial support to ensure that nuclear energy is used in a safe and secure manner, without diversion, throughout all the stages of its life cycle. It is required, in particular, to establish regulatory and operator infrastructures with adequate allocation of human, financial and technical resources, securing 3Ss (safety/security and safeguards) in all phases of nuclear power plant life cycle, i.e., design, manufacture/construction, operation, decommissioning phases, and conforming to international safety/security and safeguards norms manifested in IAEA guidelines, international agreements, conventions, etc.

In addition, the following points should be addressed as implied from proper governance perspectives:

- Nurturing safety, security, and safeguards culture;
- Promoting best practices through sharing knowledge and experience;
- Promoting international cooperation/assistance; and
- Maintaining utmost transparency/openness and adequate risk communication in order to obtain public acceptance and confidence.

IAEA report, "Milestones in the Development of a National Infrastructure for Nuclear Power,"[2] identifies the following nineteen essential issues to be addressed in establishing necessary national infrastructure, of which 3S covers the paramount part: national position, *nuclear safety,* management, funding and financing, legislative framework, *safeguards*, regulatory framework, radiation protection, electrical grid, human resources development, stakeholder involvement, site and supporting facilities, environmental protection, emergency planning, *security and physical protection*, nuclear fuel cycle, radioactive waste, industrial involvement, and procurement

The report also notes the following:

- "Past experience has demonstrated that reliance on engineered safety systems is, by itself, insufficient to ensure nuclear safety. The important lesson is that safe and secure operations can only be ensured if there is an infrastructure in place to make sure that the specific requirements of nuclear power technology are recognized and that appropriate conditions are established to deal with them safely."

In the area of safeguards, the state should establish and maintain an adequate state system of accounting for and control of nuclear materials, (SSAC), in order to exercise the required state control and to facilitate cooperation with the IAEA in implementing the provisions of the safeguards agreement and the additional protocol. SSAC constitutes an essential part of the infrastructure for assuring effective and efficient safeguards.

Security and physical protection are intended to prevent malicious acts by internal or external adversaries that might endanger the public or the environment. Infrastructure for security and physical protection of the nuclear power plant and other facilities, and nuclear material during storage and transportation need to be provided at all times.

International Initiative on 3S-based Nuclear Energy Infrastructure

Further, the importance of 3S is also fully noted in paragraph twenty-eight of Leaders Declaration at G8 Hokkaido Toyako Summit: "We reiterate that safeguards (nuclear nonproliferation), nuclear safety and nuclear security (3S) are fundamental principles for the peaceful use of nuclear energy."[3]

They recognized the following points:

- There is a growing need to establish common understanding on the importance of 3S;
- While the countries interested in nuclear energy have the responsibility for ensuring 3S, international cooperation in this field can prove beneficial, and that G8 members should take an active role in promoting such international cooperation.

Against this background, an international initiative proposed by Japan on 3S-based nuclear energy infrastructure has been launched with the following shared principles and actions to be taken:

Shared Principles

The following has been set as the shared principles of the international initiative:

- Application of nuclear energy to power generation is clearly part of the peaceful use foreseen in article IV of the NPT;
- Each state has a right to define its national energy policy;
- Peaceful use of nuclear energy accompanied by commitments to implement 3S are a sound basis for international transparency and confidence in the sustainable development of nuclear energy. Implementation of 3S constitutes an indispensable objective for the development of the infrastructure necessary for the introduction of nuclear power generation;
- While the responsibilities of ensuring 3S and developing the

necessary regulatory, legal, and administrative infrastructure rest with the countries concerned, international cooperation can greatly contribute to the development of such infrastructure;
- We duly recognize the pivotal role and function of the IAEA related to nuclear energy infrastructure development;
- On-going related national and international activities, such as the Global Nuclear Energy Partnership (GNEP), the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) and the Global Initiative to Combat Nuclear Terrorism, among others should be duly acknowledged.

Actions To Be Taken

The following actions will be taken under this initiative in cooperation with or complementary to IAEA activities:

- Sharing good practices and lessons learned in implementing our 3S-related activities to support infrastructure development as mentioned above;
- Exchanging information on on-going activities, both bilateral and multilateral, to support infrastructure development;
- Identifying challenges that have surfaced in infrastructure development;
- Identifying areas of infrastructure development that could be improved through international cooperation both bilaterally and multilaterally;
- Implementing bilateral and multilateral projects as necessary, on a voluntary basis, to support infrastructure development in accordance with our shared principles.

This initiative is aimed at raising awareness of the importance of 3S worldwide and assisting the countries concerned in developing 3S and the relevant infrastructure for the introduction of nuclear energy through international cooperation.

The IAEA has also been promoting the 3S concept, which recognizes the interface between nuclear security, nuclear safety and safeguards and tries to maximize their synergy effects.

Synergies among 3Ss

In the document, "Nuclear Security - Measures to Protect Against Nuclear Terrorism" (GOV/2006/46-GC(50)/13, dated August 16, 2006), IAEA Secretariat report to the Board of Governors and consequently to the General Conference, the IAEA provides the following examples of synergies between nuclear security, nuclear safety, and safeguards, and emphasizes their importance:

- "Security and safety measures share a common aim of protecting human life and health, and the environment. While security measures are directed at preventing, detecting, or responding to malicious acts, safety measures are designed to prevent accidents or to establish a balance between exposure to ionizing radiation and operational requirements. In developing safety standards and security guidance, and related implementation tools, the agency has sought to identify and maximize the appropriate synergies with the aim of achieving consistency and efficiency. For example, joint missions are convened to evaluate and assess the effectiveness of national laws and regulations for control of radioactive sources. As far as administration of sources is concerned, the processes are combined and the results shared. Laws and regulations applying to other aspects of nuclear security, e.g., in the criminal code or related to combating illicit trafficking, do, however, still need separate examination."
- "Other synergies can be found in engineering safety design measures which help to reduce the vulnerability of vital areas in nuclear facilities, thereby contributing to protection against sabotage."
- "Similarly, security and safeguards objectives are jointly attained by measures to enhance the control of and accounting for nuclear material. Training in implementing state systems of accounting for and control of nuclear material has been set in both a safeguards and security framework. The safeguards system in general, with its focus on deterring and detecting the diversion of nuclear material makes a key contribution to the overall nuclear security architecture and, in turn, security requirements such as early detection of theft, detection of illicit trafficking, nuclear forensics and physical protection of nuclear material, make a substantial contribution to non-proliferation objectives."
- "For its legislative assistance program, the agency has pursued a comprehensive approach, referred to as the '3S' concept, which recognizes the interface between nuclear security, nuclear safety and safeguards as well as nuclear liability."

3S-Based Infrastructure: Japanese Initiative

Japan's Efforts in Establishing 3S-Infrastructure

Under relevant laws and regulations stemming from the Atomic Energy Basic Law of 1955, Japan has attained a high standard of 3Ss, conforming to the international norms such as IAEA guidelines and international conventions.

Based on this good record and substantial experience in 3Ss, Japan has been exerting various efforts in assisting developing and other countries in establishing the required infrastructure to assure 3Ss (e.g., training courses/seminars for SSAC, nuclear safety, and nuclear security).

In the field of safeguards, nonproliferation and nuclear security, the following activities have been done by Japan in order to assist capacity building in developing countries:

- Holding ASTOP (Asian Senior-level Talks on Nonproliferation) meetings since 2003, inviting Director General level participants from Association of Southeast Asian Nations (ASEAN) 10 countries, China, Republic of Korea, the United States, Canada, Australia, and New Zealand.

- Holding regional AP Seminars since 2001 for Asia Pacific, Latin America, Central Asia, Baltic, and African countries with Japanese contributions in finance and human resources;
- Holding AP Seminar in Vietnam in August 2007 in cooperation with IAEA and Australia;
- As a JASPAS (Japanese Support Program for Agency Safeguards) task, a regional SSAC training course has been organized since 1985 almost every four years, alternately with that held by Australia, for Far East, South East Asia, and Pacific countries;
- In addition, JAEA (Japan Atomic Energy Agency) and its predecessors, PNC (Power Reactor and Nuclear Fuel Development Corporation) and JNC (Japan Nuclear Cycle Development Institute), have been organizing SSAC training courses each year until 2006, inviting participants from Asia Pacific and FSU countries;
- Since mid-September 2008, a Japanese cost-free expert has been seconded to IAEA to organize workshops, IAEA advisory services and other activities as necessary for establishing and maintaining SSAC functions for effective and efficient implementation of comprehensive safeguards agreements and APs in former Soviet Union countries and newly emerging countries of nuclear power generation, with the total funding of US$560,000 for 2008, including his salary;
- As a part of the NSF (Nuclear Security Fund) donation by Japan (US$811,862 for 2001 to 2006), the Ulba Project has been carried out in order to improve materials control and accounting and physical protection systems at the Ulba Metallurgical Plant in Kazakhstan; and
- In collaboration with IAEA, "Seminar on Strengthening Nuclear Security in Asian Countries," the first international outreach conference on nuclear security in Asia, was held in Tokyo in November 2006. Some 100 participants from nineteen countries recognized the importance of nuclear security and the need for international cooperation.

Japanese Initiative launched at the G8 Hokkaido Toyako Summit

As follow-up activities to the "International Initiative on 3S-based Nuclear Energy Infrastructure" (http://www.mofa.go.jp/policy/economy/summit/2008/doc/pdf/0708_04_en.pdf) or "3S Initiative," which was launched at the G8 Hokkaido Toyako Summit last year, G8 Nuclear Safety and Security Group (NSSG) has started its activities in cooperation with the IAEA. The process of the 3S Initiative at the NSSG will continue for five years starting from 2009. In order to facilitate the process, Japan has been designated as the coordinator of the Initiative, and will make necessary preparations in close consultation with the G8 NSSG chair each year.

Under the 3S Initiative, G8 members are also expected to implement bilateral and multilateral projects as necessary, on a voluntary basis, to support infrastructure development in cooperation with or complementary to IAEA activities. Japan, for its part, hosted a 3S-related seminar together with the IAEA in Vietnam in 2008 as follows:

- *Regional Seminar on Nuclear Security, Safety and Safeguards in Hanoi* — Based on the agreement made by Toyako G8 Summit, this seminar was held August 18-20, 2008, in Hanoi, Vietnam. The IAEA and the Japanese government hosted the seminar in order to enhance the awareness of Asian countries that it is extremely important to ensure 3Ss in embarking on the use of nuclear energy. Participants were some forty government officials from Japan, Vietnam, Bangladesh, Indonesia, Laos, Malaysia, Nepal, the Philippines, Singapore, and Thailand as well as IAEA experts. The countries from which seminar participants came have only the experience of utilizing radiation and the study for introducing nuclear energy was just initiated. In this context, it was extremely significant for Japan, the most advanced nuclear power country in the region, to share in general her knowledge and experience in 3Ss with those countries planning to introduce nuclear power.

Japan believes that while the responsibility for ensuring 3S rests with the countries interested in nuclear energy, international cooperation for ensuring 3S in those countries can prove beneficial. Japan considers holding similar seminars in other regions and is in consultation with the IAEA.

Conclusions

It is imperative for developing countries to gain the necessary support and assistance from developed countries when they embark on a nuclear power program. Their commitments to 3Ss are indispensable for assuring the transparency of and the confidence in the use of nuclear power of these countries and obtaining the understanding and the support of the international community. Once the confidence of the international community is built on the assurance of 3Ss in these countries embarking on a nuclear power program, it is highly probable for them to obtain the international assistance and support in all the sixteen issues other than 3Ss pointed out in the IAEA milestone document. From this point of view, assuring 3Ss is of utmost importance.

However, the establishment of 3S infrastructure cannot be achieved overnight. It requires the sustained efforts on the part of those countries embarking on a nuclear power program and the cooperation on the part of advanced nuclear power countries that are supporting them. Japan is committed, as the most advanced nuclear power country in the Asian region, to cooperation with the regional countries in their efforts to establish the necessary 3S infrastructures through bilateral or multilateral arrangements like the IAEA.

Kaoru Naito is a graduate of University of Tokyo, holding a master's degree in nuclear engineering. He joined the Japanese government Science and Technology Agency (STA, now merged into MEXT, Ministry of Education, Culture, Sports, Science, and Technology), in 1971 and worked mostly in the area of nuclear safety and safeguards regulations. He also twice served with the IAEA, for seven years in total. He was the director of SGDE (Division of Development and Technical Support), Safeguard Department when he left the agency in 1992. He served as a member of SAGSI (Standing Advisory Group for Safeguards Implementation), an advisory body to the director general of the agency for nine years until the end of 2006. Currently he is the vice president of INMM Japan Chapter since 2004 and a special assistant to the minister, MEXT.

Tsutomu Arai is a graduate of Yokohama City University and obtained a master of arts degree from University of Sussex, UK. He joined Ministry of Foreign Affairs (MOFA) in 1978 and has specialized in disarmament and nonproliferation, in particular. Currently he is the director of International Nuclear Energy Cooperation Division, Disarmament, Nonproliferation and Science Department, MOFA, in charge of international nuclear energy cooperation both bilaterally and multilaterally.

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The State-level Approach to International Safeguards

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Abstract

Implementation of International Atomic Energy Agency (IAEA) safeguards and the drawing of safeguards conclusions has changed dramatically over the last decade from a system focused on verifying declared nuclear material and drawing safeguards conclusions at the level of individual nuclear facilities to one that assesses the consistency of all information regarding a state's nuclear program to plan, conduct, and evaluate verification activities and to draw safeguards conclusions for the state as a whole. In the state-level approach, verification activities are no longer conducted in a mechanistic, criteria-driven manner but rather are information driven resulting in greater effectiveness and efficiency. In the state-level concept, safeguards implementation and evaluation are based on a state-level approach (SLA) and annual implementation plan (AIP) elaborated for an individual state. State-level approaches are developed on a non-discriminatory basis using generic safeguards verification objectives common to all states with comprehensive safeguards agreements (CSAs) in force. Taking state-specific features into account, such as the characteristics of the state's nuclear fuel cycle and scientific and industrial infrastructure, an acquisition path analysis is conducted in order to define state-specific technical objectives. The tools and methods available to meet these technical objectives are then specified in the state-level safeguards approach and AIP. While the SLA concept applies to all states with CSAs in force, to date formal SLAs and AIPs are being developed and implemented for states for which the broader safeguards conclusion has been drawn. Plans are underway to extend the development of SLAs and AIPs to all states with CSAs in force. The paper will describe the state-level approach concept, summarize the status of implementation and outline plans for future development.

Introduction

Under traditional safeguards,[1] IAEA activities were focused primarily on verifying nuclear material at declared locations in states with *significant* nuclear activities. The Safeguards Criteria, developed in the late 1980s, specified the verification activities to be conducted for each type of nuclear installation in order to detect the diversion of a significant quantity of nuclear material from declared use at the installation and misuse of the facility to produce undeclared material. In the context of the criteria, states with significant nuclear activities were defined as those having any amount of nuclear material in a facility or location outside facilities (LOF) and thus subject to in-field inspection activities. Safeguards conclusions were drawn and reported regarding the non-diversion of nuclear material placed under safeguards at declared nuclear facilities and LOFs. The shortcomings of a safeguards system focused essentially on declared nuclear material and safeguards conclusions drawn at the facility level became evident with the discovery of Iraq's clandestine nuclear weapons program in the aftermath of the 1991 Gulf War.

Efforts to strengthen the safeguards system, in particular the agency's ability to detect undeclared nuclear material and activities in states with comprehensive safeguards agreements (CSAs), began almost immediately. In 1992, the IAEA Board of Governors affirmed that the scope of CSAs was not limited to nuclear material actually declared by a state, but included any material that is required to be declared. Expressed differently, the board confirmed that the IAEA has the right and obligation, under such agreements, not only to verify that state declarations of nuclear material subject to safeguards are *correct* (i.e., they accurately describe the types and quantities of the state's declared nuclear material holdings) but that they are also *complete* (i.e., that they include everything that should have been declared).

In order to address the detection of undeclared nuclear material and activities in a state, it became clear that very different tools and techniques were required from those needed for the timely detection of the diversion of declared nuclear material. The strengthening measures progressively adopted, especially those of the Model Additional Protocol,[2] involve acquisition of a broader range of safeguards-relevant information, more emphasis on information analysis, broader IAEA inspector access to locations in states beyond declared facilities, use of advanced technical verification measures and a more investigative approach in implementing safeguards. Strengthened safeguards also requires emphasis being placed on considering the entire nuclear fuel cycle of a state (i.e., the state "as a whole") rather than individual facilities. The purpose of all of these measures is to increase transparency (i.e., knowledge and understanding) about a state's nuclear material, activities and plans.

State Evaluation and the Drawing of Safeguards Conclusions

The framework for this move from safeguards implementation and conclusions drawn at the facility level to implementation and conclusions drawn for a state as a whole is the safeguards state evaluation process. The state evaluation conducted for an individual state with a CSA in force seeks to answer the interrelated questions of whether all relevant information about a state's nuclear program is consistent, whether the *picture* of the state's present and planned nuclear program is complete, and whether sufficient information is available about a state's nuclear activities and plans to enable the IAEA to provide credible assurance, through its safeguards conclusions, that the state is complying with its safeguards obligations.

The information acquired and assessed in this broad-based state-level evaluation includes information: (i) provided by the state under its safeguards agreement, additional protocol or voluntarily; (ii) derived from IAEA in-field verification activities; and (iii) obtained from open and other sources. The information provided by the state on its nuclear program (both current and planned) is assessed to determine whether it is internally consistent and then is compared with all other relevant information available to the agency. This consistency analysis aims to detect possible indications of diversion of declared nuclear material or of undeclared nuclear material or activities in the state. As described in another article in this *Journal*,[3] the types of information acquired by the agency and the analyses conducted continue to expand and evolve. Critical to the state evaluation process is the identification of anomalies or inconsistencies requiring follow-up through e.g., the acquisition of additional information or the conduct of in-field verification activities. Defining and conducting appropriate follow-up activities is essential in order to ascertain whether the identified anomalies and inconsistencies indicate the possible presence of undeclared nuclear material or activities or the diversion of nuclear material from peaceful activities.

These state-level evaluations provide the basis on which the agency draws its safeguards conclusions reported annually to the Board of Governors and the international community. For states with CSAs and additional protocols in force, a safeguards conclusion that all nuclear material has remained in peaceful activities in a state is based on the Secretariat's finding that there are no indications of diversion of declared nuclear material from peaceful nuclear activities and no indications of undeclared nuclear material or activities in the state as a whole. Because the information and access provided under an additional protocol are essential for the agency's ability to provide credible assurance of the absence of undeclared nuclear material and activities for the state as a whole, the safeguards conclusion drawn for a state with a CSA alone relates only to the non-diversion of declared nuclear material from peaceful activities.

Safeguards conclusions are drawn and reported annually for every state with a safeguards agreement in force. In addition to the approximately seventy-five states with significant nuclear activities where routine safeguards inspections are conducted, there are some eighty-five states with minimal or no nuclear activities. The majority of these states have concluded a small quantities protocol (SQP) to their CSA. For a state with an operative SQP based on the original model set out in 1974, the implementation of important safeguards measures related to the provision of information and access to nuclear locations that are implemented routinely in other states with CSAs are held in abeyance. In 2005, the Director General drew the Board of Governors' attention to the limitations of such SQPs and the resulting weakness in the safeguards system, particularly in the basis on which safeguards conclusions are drawn and reported for such states. The board agreed and decided in September 2005 that SQPs should be subject to modifications in the standard text and a change in the SQP criteria. The changes endorsed by the Board have the effect of (i) making an SQP unavailable to a state with an existing or planned facility; (ii) requiring states to provide initial reports on nuclear material and notification as soon as a decision has been taken to construct or to authorize construction of a nuclear facility and (iii) allowing for agency inspection. The Secretariat continues to communicate with states to implement the Board's decisions. As of March 2009, nineteen states have amended operative SQPs and fifty-eight states have operative SQPs that require amendment.

Developing a State-level Approach

The comprehensive state evaluations conducted for individual states provide the basis for a state-level approach to safeguards implementation where verification activities can be planned and conducted, results evaluated, and follow-up actions identified for each state individually. In the state-level concept, safeguards implementation and evaluation are based on a state-level approach and annual implementation plan elaborated for an individual state. State-level approaches are developed on a non-discriminatory basis using generic safeguards verification objectives common to all states with CSAs. Taking state-specific features into account, such as the characteristics of the state's nuclear fuel cycle and scientific and industrial infrastructure, an acquisition path analysis is conducted in order to define state-specific technical objectives. The tools and methods available to meet these technical objectives are then specified in the state-level approach and annual implementation plan, which helps to ensure a transparent and non-discriminatory system.

Generic State-level Safeguards Objectives

The agency designs and implements its verification activities in order to meet three generic safeguards objectives at the state level. Common to all states with CSAs, these three objectives are: (A) to detect undeclared nuclear material and activities in the state as a whole; (B) to detect undeclared production or processing of nuclear material at declared facilities and LOFs; and (C) to detect diversion of declared nuclear material at declared facilities and LOFs. While it is recognized that these three objectives are interrelated, considering them separately facilitates the planning and evaluation of safeguards implementation. An activity common, and important, to all three objectives is the follow-up of anomalies and inconsistencies identified in performing the activities necessary to meet the objectives.

Acquisition Path Analysis

As described in paragraph 2 of INFCIRC/153 (Corr.),[4] safeguards under a CSA are applied for the exclusive purpose of verifying that nuclear material in peaceful nuclear activities is not diverted to nuclear weapons or other nuclear explosive devices. In order to apply effective safeguards under CSAs, the agency needs to consider all potential pathways for a state to acquire or produce nuclear material for use in a nuclear explosive device. Such an acquisition path could involve the diversion of declared nuclear material, the unreported production or processing of nuclear material at declared nuclear facilities, and/or undeclared nuclear material and activities.

For a specific state, possible acquisition paths are identified based on state-specific information on the state's nuclear capabilities identified in the state evaluation. This includes information on: (i) the state's nuclear fuel cycle infrastructure including facilities, types and quantities of nuclear material, and fuel cycle research and development (R&D) activities; (ii) uranium/thorium deposits, mining and concentration; (iii) technological and industrial capabilities including manufacture of additional protocol Annex I items; and (iv) scientific and nuclear research and development. Other state-specific factors are considered when assessing the plausibility and risk associated with the identified acquisition paths including: (i) the dependence of the state's nuclear activities on other states (e.g., no indigenous supply of uranium; no indigenous fuel fabrication capabilities); (ii) the international interdependence of fuel cycle facilities (e.g., multinational ownership, management and operation); and (iii) the state's acceptance of and demonstrated commitment to non-proliferation norms.

State-specific Technical Objectives

To define state-specific technical objectives, the plausible acquisition paths are assessed and objectives defined to ensure detection of each pathway. Technical objectives are defined by where the objective is to be addressed (facility, site, other location) and what nuclear material or activity would be involved. Examples of such technical objectives are the detection of undeclared conversion at mines and concentration plants or the detection of undeclared enrichment at any location in the state other than declared enrichment plants. Using the Physical Model of the nuclear fuel cycle,[5] signatures and indicators associated with diversion or undeclared activity can then be identified and possible verification measures to detect them specified.

Safeguards Measures

The suite of tools available to detect the indicators associated with the identified acquisition paths for a specific state include both quantitative verification measures as well as more qualitative techniques. These tools are ever evolving and improving. Safeguards measures to detect undeclared nuclear material and activities outside of declared facilities and LOFs include information analysis (including information regarding nuclear-related trade), satellite imagery, and in-field technical measures (e.g., environmental sampling, visual observation, production records review, radiation measurements) conducted during complementary access or technical visits. Detection of diversion or of undeclared production or processing of nuclear material at declared facilities and LOFs can be achieved through *inter alia* nuclear material accountancy verification (records review, item counting, verification measurements, sampling for destructive analysis), containment and surveillance, installed monitoring systems, environmental sampling, design information verification and complementary access.

Formulation of Technical Objectives and Safeguards Measures—Illustrative Example

To illustrate the formulation of state-specific technical objectives and the identification of the safeguards measures to meet these objectives, consider a state operating a research reactor at an R&D complex. Assume the state also possesses quantities of nuclear material that have been exempted from safeguards accounting procedures. The following is an example of an acquisition path for the state using exempted material: (i) undeclared manufacture of targets from the exempted material; (ii) undeclared irradiation of the targets in the research reactor at the declared R&D complex; (iii) undeclared extraction of small quantities of plutonium from the irradiated targets in the radiochemical laboratory at the declared R&D complex; and (iv) use of the extracted plutonium for clandestine R&D aimed at acquiring knowledge in the manufacture of a nuclear explosive device. The specific technical objectives to address this acquisition path would be to: (i) detect undeclared processing of exempted material into targets; (ii) detect misuse of the research reactor for undeclared irradiation; (iii) detect undeclared separation of plutonium at the declared R&D complex; and (iv) detect indicators of R&D in the field of nuclear explosive devices. The associated indicators of this acquisition path would be (i) use of exempted material not consistent with the exemption purpose; (ii) deviations in the core configuration and operation of the research reactor as well as unrecorded nuclear material in the core or cooling pond; (iii) radiochemical laboratory equipment not consistent with declared activities and the presence of unrecorded nuclear material; and (iv) research in the field of nuclear explosive devices. Finally, the possible safeguards measures to detect this acquisition path would include both evaluation activities at Headquarters (specifically, the general state evaluation and analyzing the declared operational cycles and fuel consumption of the research reactor) and in-field verification activities (specifically, complementary access at locations with exempted material to look for undeclared activities and unannounced inspection with design information verification (DIV) at the research reactor and radiochemical laboratory to detect undeclared processing/production of nuclear material).

State-level Approach and Annual Implementation Plan

The state-level approach defines the set of verification activities necessary to address the plausible acquisition routes and meet the technical objectives for an individual state. The set of possible safeguards measures identified for implementation both in the field and at Headquarters are further customized for a state by taking into account other factors such as the interaction between facilities in the state, the effectiveness and cooperation of the state system of accounting for and control of nuclear material (SSAC), the ability to conduct unannounced inspections effectively, and the agency's experience with safeguards implementation for the state. Because a state-level approach provides for a degree of freedom in planning verification activities such as complementary access, unannounced or short notice inspections, DIV, and physical inventory verification for certain types of facilities, an annual implementation plan is developed setting out the specific activities planned for implementation during a specific year.

Current Status

At this point in the development and implementation of the state-level process, formal state-level approaches and annual implementation plans are being prepared, approved, and implemented for states where the broader safeguards conclusion has been drawn. Because of the increased assurance of the absence of undeclared nuclear material and activities resulting from the implementation of the Additional Protocol in such states, further efficiencies in safeguards implementation can be realized. Specifically, inspection activities at the state's declared nuclear facilities and LOFs can be less intense than those in states without the broader conclusion. This optimized combination of safeguards measures available to the agency under CSAs and the additional protocol for maximizing effectiveness and efficiency is known as integrated safeguards. For each such state, a state-level integrated safeguards approach is developed and approved and an annual implementation plan elaborated at the beginning of each year. The annual implementation plan is reviewed to ensure its consistency with the corresponding state level integrated safeguards approach and that all outstanding follow-up actions will be addressed. In evaluating integrated safeguards implementation for a state, the Secretariat assesses the extent to which the planned activities have been carried out and the objectives of the state-level approach achieved. In addition, the Secretariat monitors the status of follow-up actions, including the actions necessary in order to conclude whether or not the identified anomalies and inconsistencies constitute an indication of diversion of declared nuclear material or the presence of undeclared nuclear material or activities. As of March 2009, integrated safeguards were being implemented for thirty-six states.

For states with both a CSA and an Additional Protocol in force, but no broader conclusion drawn, safeguards are implemented according to the Safeguards Criteria and the existing guidelines for additional protocol measures. For the majority of these states, a *roadmap* to drawing the broader conclusion exists that includes addressing issues at the state level. For states with only a CSA in force, safeguards implementation is based on the Criteria. Even in the absence of formal state-level approaches for these states, safeguards activities are planned, conducted and evaluated and follow-up actions identified taking into account all safeguards-relevant information for each state. As described above, state evaluations are conducted for all states as a basis for annual safeguards conclusions.

With regard to development of the state-level concept and approach, to date some forty-three technical objectives and indicators have been defined as sub-objectives to the three generic state-level objectives identified above. Work is underway to link these technical objectives and indicators with specific safeguards activities followed by linking the safeguards activities with specific equipment or technology that might be used for detection. The IAEA's Novel Technology Project has identified strong indicators and signatures associated with specific nuclear fuel cycle processes. These will be used to facilitate nuclear safeguards technology gap analyses, allowing prioritization and identification of technologies for development of future safeguards applications.

Future Developments

In the near-term, the goal is to develop and implement formal state-level approaches and annual implementation plans for all states with CSAs in force. In addition, a more transparent evaluation process for determining the effectiveness of state-level approaches and annual implementation plans in achieving the state-specific technical objectives is being developed along with a consolidated set of internal guidelines and procedures for documenting the implementation of the state-level approach concept. As part of the Department of Safeguards' *Action Plan for Meeting IAEA Safeguards Needs in the 2020s,* medium-term strategies include consideration of a broader range of state-specific factors, including the ability to establish risk-based priorities when identifying acquisition paths and verification activities, in order to more fully realize a truly information-driven safeguards system.

Conclusion

Considerable progress has been made in the development and implementation of the state-level approach to safeguards in which all information about a state's nuclear program and activities is used to plan, conduct, and evaluate verification activities and to draw safeguards conclusions for the state as a whole. In the state-level approach, verification activities are no longer conducted in a mechanistic, criteria-driven manner but rather are information driven resulting in greater effectiveness and efficiency. State-level integrated safeguards approaches are currently being implemented for thirty-six states. Plans are underway to develop and implement state-level approaches for all states with CSAs in force. To more fully realize information-driven safeguards through the state-level approach concept, further developments in evaluation, risk assessment, and state-specific factor consideration are necessary.

Notes

1. "Traditional safeguards" refers to safeguards implementation prior to the introduction of safeguards strengthening measures beginning in the mid-1990s.
2. Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards, INFCIRC/540 (Corr.), 1998.
3. Baute, J. International Atomic Energy Agency, *The Challenges of Non-Proliferation Information Analysis.*
4. The Structure and Content of Agreements between the Agency and States required in Connection with the Treaty on the Nonproliferation of Nuclear Weapons, INFCIRC/153 (Corr.), 1972.
5. Developed by the Secretariat in collaboration with experts from several Member States, the Physical Model of the nuclear fuel cycle identifies, describes, and characterizes every known technical process for converting source material to weapon usable material and identifies indicators for each process in terms of equipment, nuclear material and non-nuclear material.

Implementing the State-level Approach: Moving Forward

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The views expressed here are those of the author.

Abstract

The state-level approach provides a new foundation for safeguards implementation and evaluation. This represents a fundamentally new direction for the International Atomic Energy Agency (IAEA) safeguards system—one that provides for enhanced effectiveness (in terms of better focusing safeguards effort) and efficiency (in terms of better utilization of IAEA verification resources). While the state-level approach is being applied to all states with safeguards agreements, the optimization of the approach can only be achieved for a state with both a Comprehensive Safeguards Agreement and an Additional Protocol in force and for whom the agency concludes that the declared nuclear material in the state has not been diverted and provides credible assurance of the absence of undeclared nuclear material and activities in the state as a whole. On this basis, the agency can move to a state-level integrated safeguards approach. Canada achieved this broad conclusion for the first time in September, 2005 and it has been maintained annually since that time. Accordingly, the IAEA and the Canadian state system of accounting and control have been pursuing the implementation of a state-level integrated safeguards approach for Canada. The initiative is well-advanced and the target for completion remains mid-2009. This paper will discuss the state-level approach in the context of the next steps in international safeguards. In doing so, it will briefly outline the primary elements of the concept and identify some considerations relevant to the continued evolution of the approach. Finally, the paper will review, in general terms, the application of the approach to Canada thereby providing a country-specific context to the evolving conceptual framework.

The State-level Concept

The development and implementation of the state-level safeguards concept over the past decade represents a fundamental change to the International Atomic Energy Agency's (IAEA) safeguards system.

During this period and continuing to this day, the IAEA is seeking to gain an accurate and comprehensive understanding of the nuclear fuel cycle and related activities in individual states. The objective is to expand the Secretariat's activities beyond the verification of declared nuclear material at declared facilities to include an assessment of the consistency of information on a state's entire nuclear program and related activities. Accordingly, many of the safeguards strengthening measures, especially those set out in the Additional Protocol (AP), provide the Secretariat with enhanced information about a state's activities and enhanced access to locations within a state.

In addition to state-supplied information, the utilization of technologies such as satellite imagery, the significant increases in the quantity and quality of information available via open sources and other means, and enhanced analytical capabilities all contribute to expanding the Secretariat's knowledge of a state's nuclear program. This knowledge feeds into the very comprehensive and dynamic state evaluation process, which provides the basis for planning safeguards activities in a state, for drawing the annual safeguards conclusion about a state and for reporting on safeguards implementation and evaluation to the Board of Governors, to the state, and to the international community at large.

This, in essence, is the state-level concept. Currently, the Secretariat is applying the concept to all states. Individual state evaluation reports are being prepared for every state and these reports are being reviewed annually in the context of drawing safeguards conclusions and determining inspection effort.

While general application is being pursued, the greatest expression of the state-level concept can be found in those states with both a comprehensive safeguards agreement (CSA) and an AP in force and for whom the Secretariat has drawn the conclusion that all nuclear material in the state remains in peaceful activities. In these circumstances, the state-level concept is linked to the concepts underlying integrated safeguards. Accordingly, the IAEA can implement unique state-level integrated safeguards approaches that are based upon agreed model frameworks at both the state and the facility level and which can maximize the use of state-specific characteristics in the context of safeguards implementation and evaluation.

In the 2007 Safeguards Implementation Report (SIR) the Secretariat noted that, of the eighty-two states that had both a CSA and an AP in force, 57 percent had received the broad safeguards conclusion. This segment will continue to grow and will represent the primary safeguards environment for the IAEA in the not too distant future. To date, progress in the introduction of state-level integrated safeguards approaches in countries with the broad safeguards conclusion, particularly in those states with significant fuel cycle activities, has been slow. However, one can expect the rate of progress in this area to increase as the Secretariat gains experience in undertaking the requirements necessary to transition to these approaches.

The next two sections of the paper briefly explore some of the inherent benefits of state-level integrated safeguards approaches and discuss some of the challenges associated with optimising those benefits.

The Benefits of State-level Integrated Safeguards Approaches

State-level integrated safeguards approaches are information-driven. The information is derived from many sources, some initiated by the Secretariat through its own information gathering and analysis processes, some provided from sources other than the state itself and some provided by the state. This latter category of information is very significant and distinguishes state-level integrated safeguards approaches from the general application of the state-level concept. For states under integrated safeguards, the Secretariat has more state-supplied information than ever before. While the scope and volume of this information is impressive, the timelines being established for the provision of this information are also very important, particularly for a state with a significant nuclear program. For example, some state-level integrated safeguards approaches feature the near-real-time provision of information by the state on the flow of nuclear material through the fuel cycle facilities of the state. When this timely information is supported by remotely monitored safeguards equipment which incorporates state of health capabilities and with greater access rights for IAEA inspectors to locations within a state, the result is a comprehensive, up-to-date picture of what is happening within the state.

The information noted above, coupled with the Secretariat's analytical and verification activities, provide the basis for a *more risk-informed approach* to safeguards implementation and evaluation. This risk assessment moves beyond the traditional considerations of nuclear material type and quantity to include broader state-level considerations, such as a state's demonstrated commitment to nuclear non-proliferation and the high level of cooperation between the state and the IAEA in facilitating safeguards implementation and in addressing questions and inconsistencies. In this regard, trending analysis becomes an important tool; that is, looking at and evaluating state behaviour over an extended period of time. While not a definitive indicator in terms of the state's future actions and policy directions, a prolonged pattern of consistent, appropriate behaviours should factor significantly into any risk assessment of the state and the determination of appropriate verification effort to address that risk. The fact of the matter is that the majority of states make and adhere to their comprehensive commitments to nonproliferation and this needs to be better reflected in the application of safeguards in those states. The lessons learned from positive experiences, although frequently overlooked, are often as important as those learned from negative experiences.

Non-discrimination is a fundamental condition of a credible safeguards system. However, it must be recognized that differentiation based upon defensible decisions supported by clear and transparent processes is not discrimination. State-level integrated safeguards approaches will lead to a *differentiated safeguards system*—one that reflects the specific technical and non-technical characteristics of a state. The nature, scope and frequency of verification activities will vary from state to state. Furthermore, the nature, scope and frequency of such activities within a given state will vary from year to year as set out in the annual implementation plan for that state.

Unpredictability in terms of the verification activities to be conducted in a state is a key element of state-level integrated safeguards approaches. This means that the timing, location, and intensity of verification activities will not be known to the state or to the facility operators. The capability of implementing such an approach in a state is of considerable value for targeting safeguards effort and for contributing to high levels of confidence that the information provided by the state is consistent and accurate. This, in turn, supports greater confidence in the IAEA's safeguards conclusions.

Optimizing State-level Integrated Safeguards Approaches

The transition to this new safeguards system is a work in progress. The Secretariat has already expended considerable effort in establishing the processes supporting the system, such as the model integrated safeguards approaches and the guidelines for their implementation. Likewise, considerable effort has been devoted to the evaluation side of the state-level approach. New processes have been established for the gathering and analysis of information relevant to the state from a safeguards perspective. The main elements of the state evaluation report process have been identified and are operational.

However, in order to optimize the benefits inherent in state-level integrated safeguards approaches several challenges will need to be addressed. These include: (i) establishing the correct balance between quantitative and qualitative elements in both safeguards implementation and evaluation; (ii) strengthening the IAEA's capabilities to provide credible assurance regarding the absence of undeclared nuclear material and activities; (iii) ensuring consistency and transparency in the processes that underlie the state-level integrated safeguards approaches and in the application of those processes; and (iv) ensuring appropriate reporting on the implementation of the state-level approach and the results derived therefrom.

The Quantitative/Qualitative Mix

With respect to the quantitative/qualitative mix, one of the greatest challenges will be to reconsider the amount of inspection effort needed to verify nuclear material declarations.

While nuclear material accountancy is a fundamental element of the safeguards system, optimisation will be elusive if too much emphasis continues to be placed on these considerations at the facility level rather than at the state level. Changes have been made, but the context for those changes has been in relation to the criteria approach—for example, initial considerations of integrated safeguards approaches and the policies and procedures that support them focused on the determination of the amount of variance from traditional goal attainment objectives concerning timeliness and quantity that would be acceptable. This led to serious consideration of adjustments to traditional approaches to inspection, including frequency, nature and coverage.

While this probably was an appropriate starting point, further consideration must include a more strategic perspective to optimize state-level integrated safeguards approaches. For example, verification effort in a state should more appropriately reflect non-technical state-level considerations; that is, considerations not related to fuel cycle characteristics and quantity and type of nuclear material. This is not to be construed as minimizing the importance of nuclear material accountancy. It is simply recognising that the application of this measure to the determination of inspection effort must be in the context of all of the other information that the Secretariat has about a state's activities. In effect, this means that the traditional assessment of the risk of diversion of nuclear material by a state should be balanced by a broader assessment of the risk of proliferation posed by the state.

Optimization will also require that the model facility and state-level integrated safeguards approaches be reviewed periodically to ensure that they provide a sufficient range of options for implementation.

Strengthening Capabilities

There will be a continued need for a robust IAEA toolbox that contains a variety of tools to be used in specific circumstances, as well as in general application. Installed or portable equipment for measuring the flow of nuclear material through large and small scale enrichment and reprocessing plants will be particularly important. Enhancing current remote monitoring systems and developing new ones will also be a priority. Furthermore, the greater utilization of periodic, short notice inspections driven by analysis and undertaken at a few facilities within a state (rather than routine inspections at all facilities) heightens the need for enhanced equipment reliability and, in some cases, portability.

The importance of the IAEA using state-of-the-art verification technology, particularly for the detection of clandestine nuclear activities, should not be under estimated. Continued emphasis will need to be placed on enhancing the IAEA's capabilities to detect undeclared nuclear material and activities through such means as satellite imagery, environmental sampling and information analysis. On the latter point, effective analytical tools will be required to cope with the increasing amount of information being generated and to avoid paralysis by analysis.

The development of new equipment and technologies should reflect and be consistent with the evolution of the IAEA's safeguards approaches. In other words, the safeguards approaches should drive the equipment development. This will require enhanced coordination and cooperation among member state support programs and between the support programs and the Secretariat. Consideration should also be given to enabling the Secretariat to direct some of this work through, for example, an independent research and development program.

Enhancing Transparency

The uniformity and rigidity that characterizes the facility-oriented, criteria-driven approach is being replaced by differentiation, adaptability, and unpredictability, supported by model safeguards approaches, expert judgment, and formal processes for the collection, analysis and storage of information on individual states. Clear and transparent processes will be required—including those used for state evaluation, for developing individual state-level integrated safeguards approaches, and for determining the annual inspection effort to be undertaken in a state—to address concerns about credibility and, as noted above, discriminatory practices. An important aspect of this element of optimization is the development of a framework that would link general state-level safeguards objectives to specific safeguards activities in a state in a way that reflects the establishment of risk-based priorities.

Ensuring Appropriate Reporting

The establishment of appropriate processes within the Secretariat to provide the foundation for the optimisation of state-level integrated safeguards approaches is a necessary but not a sufficient condition. This effort must be matched by increased effort in clearly explaining these processes and the results achieved through their implementation to the international community as a whole.

Improvements to the nature and scope of the reporting in the annual SIR must continue. Such reporting must continue to evolve to match the transition to state level approaches. Considerably more information will be required to support the Secretariat's safeguards conclusion on a state-by-state basis.

Enhanced reporting on issues of non-compliance will also be necessary. In this regard, the distinction between "intentional non-compliance" and "operational oversight" may become increasingly important. For example, as a state undertakes an increasing number of reporting obligations, the possibility for unintentional error by the state also increases. Similarly, unannounced or short notice access by IAEA inspectors will undoubtedly create some occasional, unforeseen difficulties.

Finally, appropriate reporting also pertains to the state as well as to the Secretariat. Clearly, accurate and timely reporting by the state will continue to be an important element of optimisation. This will require, *inter alia,* the establishment of effective and secure lines of communication, particularly for the provision of near-real-time reporting on the use of nuclear material across the state's entire nuclear fuel cycle.

Other considerations

The necessity for effective state and/or Regional Systems of Accounting for and the Control (SSAC/RSAC) of nuclear material remains. SSACs/RSACs must be competent and capable of meeting safeguards obligations. The effectiveness and the capabilities of such bodies will also be a significant factor in assessing the possibility for enhanced cooperation between a state or states and the IAEA—a feature of optimisation. As noted in recent SIRs, ensuring SSAC/RSAC effectiveness continues to be a significant challenge for safeguards implementation.

The development of international nuclear fuel cycle facilities will undoubtedly present a number of safeguards challenges. One important element will be the assessment of the impact on the state-level approach for a state that hosts or participates in such endeavours.

The Canadian Case: Some Considerations

Canada's nuclear power program is based upon natural uranium fuelled, heavy water moderated reactors. The Canadian nuclear fuel cycle includes: uranium mining and milling; refining and conversion; fuel fabrication; nuclear power reactors; spent fuel storage; and research and development activities. The *State-level Integrated Safeguards Approach for Canada* was approved in December 2005, shortly after Canada received the broad safeguards conclusion. The approach divides the Canadian fuel cycle into four sectors: Sector 1 includes the conversion and fuel fabrication facilities, the nuclear power reactors and the active spent fuel dry storage facilities; Sector 2 covers the Chalk River Laboratories; Sector 3 includes research reactors, locations outside facilities and static dry storages; and Sector 4 includes mines and mills and decommissioned facilities. The frequency for inspection, design information verification and complementary access is determined on a sector by sector basis. The primary state specific characteristics noted in the approach are the presence of an IAEA Regional Office in Toronto, the use of a mailbox approach to provide near-real-time reporting on a facility basis, and the use of short notice random inspections and unannounced inspections. The continued use of extensive remotely monitored containment and surveillance equipment, which includes state of health information, is another feature of the approach.

As of this writing, integrated safeguards approaches are being applied to all fuel cycle activities with the exception of those at the Chalk River Laboratories and the transfer of spent fuel to dry storage at the two single unit power reactors. According to the *state-Level Integrated Safeguards Approach for Canada,* it is expected that full implementation of the approach will reduce annual person days of inspection (PDIs) from approximately 1,100 to approximately 750. Most of this reduction is associated with one specific activity; i.e., the implementation of an integrated safeguards approach to spent fuel transfers at the multi-unit power reactors.

The state-level integrated safeguards approach for Canada was one of the first such approaches developed by the Secretariat. In many respects it is progressive. However, implementation experience to date provides some specific insights as to the possible evolution of state-level integrated safeguards approaches in line with the considerations noted in this paper. In essence these insights point in the direction of making better use of all of the information available to IAEA in determining the frequency and location of inspections and in addressing implementation issues, thereby reducing the tendency to focus on facility specific considerations. For example, implementation of the current approach places considerable emphasis on verification activities at the natural uranium refinery at Blind River based upon a determination that this facility, as the first step in the Canadian fuel cycle, is of considerable strategic significance with respect to the flow of nuclear material. While not disputing the assessment of the role of this facility, greater recognition of other factors could result in a less fulsome use of IAEA resources at this location. Those factors include: the low proliferation significance of natural uranium; the absence of enrichment or reprocessing capabilities in Canada; and the provision of near-real-time information on the flow of nuclear material through the entire fuel cycle, including the refinery, coupled with the capability of verifying that information at any facility on a short notice or, in some cases, unannounced basis.

Similarly, under the current approach for scheduling and implementing unannounced inspections, the IAEA targets specific items for verification. The unavailability of the specific item as a result of an unforeseen change in the operator's schedule causes difficulties for the IAEA, particularly in terms of the application of traditional approaches to statistical analysis. One way to address these difficulties is not to target specific items identified in the advance information provided by the operator (sometimes well in advance of the scheduled activity—for instance the proposed transfer of a specific dry storage container from the reactor to the dry storage facility) but to use random short notice or unannounced inspections to confirm that the activity or inactivity is consistent with notifications by the operator. This information can be matched with ongoing declarations concerning nuclear material in the country to enable the IAEA to focus on the complete picture for the country as a whole rather than the narrower facility-specific picture.

Finally, given the absence of enrichment and reprocessing in Canada, it may be more appropriate to concentrate inspection effort on those elements of the fuel cycle that are more strategically significant such as direct use material or activities associated with the use of direct use material. For the other elements of the fuel cycle, as noted above, the Secretariat would continue to analyse information on nuclear material accountancy to ensure consistency with the declared program and allocate inspection effort on a state level, random basis (e.g., random physical inventory verification with randomness determined at the state level rather than the facility or sector level).

Conclusions

The current and foreseeable challenges facing the IAEA's safeguards system are significant. These include: (i) maintaining a credible system that identifies and appropriately addresses noncompliance issues; (ii) effectively meeting anticipated new requirements arising from the expansion of nuclear energy, the broadening of safeguards implementation in nuclear weapon states, and the possible new verification activities arising from disarmament initiatives; and (iii) ensuring that the resources that are available to the Secretariat to carry out its verification mandate are used effectively and efficiently.

The state-level approach can contribute greatly to the IAEA's capability to meet these challenges. The extent to which it does so, however, will depend upon the extent to which the Secretariat maximizes the strengths inherent in the approach, particularly those arising from state-level integrated safeguards approaches. While considerable work has been undertaken already by the Secretariat in developing the state-level approach and the various approaches associated with integrated safeguards, further work is required. A central element of this work should be the development of a new risk framework to be applied to the determination of verification effort to be undertaken in each state—one that more appropriately balances technical factors such as nuclear material and fuel cycle considerations with non-technical factors such as a state's demonstrated commitment to nuclear nonproliferation and its cooperation with the IAEA in implementing its safeguards agreement. This framework will influence how the IAEA's safeguards system is applied in each state; for example, in determining the amount of verification effort required on an annual basis. Application of this new framework can be undertaken, for the most part, within existing approaches. However, the current approaches, as well as the policies and guidelines which support them, need to be re-examined to ensure that they reflect the essence of the new framework.

The state-level approach to safeguards planning, implementation, evaluation and reporting can provide the basis for a more *adaptable* and focused safeguards system—*adaptable* in terms of the nature, frequency and intensity of verification activities to be undertaken and *focused* in terms of the locations where the activities will be undertaken. The continued evolution of the safeguards system in this direction will be a positive step forward.

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The Euratom Safeguards System: An International Perspective

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Abstract

The European Commission, through its system of regional safeguards established in the Euratom Treaty, has worked in close cooperation with the International Atomic Energy Agency (IAEA) for several decades ensuring that both organizations are able to meet their respective safeguards requirements and draw their own independent conclusions. Since concluding the European Union (EU) safeguards agreement in 1973, there have been a number of challenges that have tested this cooperation; the implementation of integrated safeguards is the latest of these, and one that is currently well on the way to being met in full.

The commission, in consultation with its member states, has recently completed a thorough review of Euratom Treaty safeguards leaving it well placed to continue providing the required assurances on the use made of nuclear material in the EU. The resultant approach is focused on the entire nuclear fuel cycle—including the civil nuclear material in the weapons states—and enables due account to be taken for the cross-cutting aspects of security and supply.

Integrated safeguards arrives in the EU with good timing; coinciding with a number of new nuclear installations, numerous new proposals for reactor build, and with the renewal of a broader cooperation agreement between the European Commission and the IAEA, signed during a meeting between the president of the European Commission and the Director General of the IAEA in May 2008.[1] Despite the resource saving that will be achievable under integrated safeguards, the anticipated future expansion of the EU nuclear industry is likely to challenge IAEA safeguards resources to the full. It is in this light, that a much wider role is envisaged for Euratom safeguards, not just in the EU but also in the international arena. It is suggested that more effective use could be made of Euratom inspections thus enabling further IAEA resource savings. The IAEA could make better use of the commission's comprehensive safeguards activities in the civil fuel cycles of the EU nuclear weapons states. Due account should be taken of the commission's strengthened system of verification of operator nuclear material accounting and control systems. Euratom safeguards cover the entire EU and already involve direct contact and coordination with third countries worldwide. This latter level of cooperation should be enhanced providing assurances that can be fully taken into account by the IAEA.

Last but not least, the European Commission has declared its support to the IAEA in the whole area covered by the international nonproliferation regime, including the provision of assurances of supply, an issue that is considered essential for the future development of the use of nuclear power worldwide.

Background

The roots of nuclear safeguards go back more than fifty years and were founded upon the need for nuclear materials to be strictly supervised in much the same way that other precious materials were being controlled. Safeguards have always been intended to provide assurances of both an economic and political nature. While international nonproliferation aspects are at the forefront of nuclear safeguards for strategic reasons which need hardly be stressed, concerns relating to security and supply must not be neglected. Such concerns have and will always play an important role in Euratom safeguards.

Safeguards were established by the Euratom Treaty,[2] which was concluded in 1958 by the original six member states of the European Atomic Energy Community. Chapter VII of the Treaty establishes the objectives of Euratom safeguards, which can be briefly summarized as follows:

a) that nuclear materials are not diverted from their intended uses as declared by the users;

b) that provisions relating to particular safeguarding obligations assumed under an agreement concluded with third state or an international organization are complied with.

Euratom safeguards were established around the same time as the International Atomic Energy Agency (IAEA). The main purpose was to provide assurance to states supplying nuclear materials to European states that these materials would be under an international safeguards control system, used exclusively for peaceful purposes. The subsequent cooperation with the IAEA in Safeguards was agreed when the Nonproliferation Treaty (NPT) was drawn up and implemented. The ensuing safeguards agreement for the EU derives closely from the model agreement (INFCIRC/153) but contains specially drafted articles and in particular a protocol that takes into account the multinational nature of Euratom safeguards. This agreement (INFCIRC/193)[3] defines mutual obligations undertaken by the Community (and its member states) and the IAEA. In order to maintain the integrity of Euratom, and in line with Article III[4] of the NPT, the agreement dealt with a group of states rather than individual ones and enabled the IAEA to perform safeguards in EU member states taking due account of the effectiveness of the Community's system of safeguards. It is worthwhile recalling at this point that the EU system in general, is based upon communities with a unique institutional organisation, an important feature of which is the transfer of powers normally the exclusive province of state sovereignty. In the case of nuclear safeguards, the Euratom Treaty entrusts responsibility to the European Commission and traditionally to the Directorate General responsible for EU energy matters, in particular. Under Euratom Treaty safeguards, each signatory member state voluntarily hands over responsibility for safeguards within its own territory to the community executive body, the commission.

The commission is concerned with satisfying itself that nuclear materials are not diverted from their declared intended uses and deals directly with nuclear operators. Euratom safeguards are applied equally in non-nuclear weapons states and in the civil fuel cycles of the EU nuclear weapon states, i.e., France and the UK. Euratom safeguards have several interfaces and cross-cutting aspects with nonproliferation, security and supply. An assurance is also required that obligations assumed by the Community under an agreement concluded with a third state or an international organization are complied with. The former is basically ensuring obligations relating to peaceful use towards supplier states, the latter relates primarily to cooperation with the IAEA under the relevant comprehensive safeguards agreement and the similar agreements involving France and the UK.

The EU stands today at twenty-seven member states and accounts for approximately 35 percent of the world's nuclear capacity. The objectives, political weight and institutional capacity of Commission's safeguards body make it an important player in the international safeguards field.

The Evolution of IAEA Cooperation

While the original interpretation of the safeguards agreement saw the IAEA inspectors drawing their own independent conclusions on the basis of observing Euratom inspectors during Euratom scheduled inspections, this has changed significantly over the years. Joint teams were established within several years of accession for those installations handling significant amounts of HEU or plutonium, and in enrichment plants. A significant change occurred in 1992 with the agreement between the Commission and IAEA on a "New Partnership Approach"—NPA[4]—with its broad objective of enhancing EU safeguards efficiency and effectiveness. An important factor was the desire to make use of the regional nature of the Euratom system and save IAEA resources. Inspection activities were performed on the basis of "one-job-one person"—replacing observation and joint team. Greater use of technology was foreseen in order to reduce the physical presence of inspectors to a minimum.

Shortly after the introduction of NPA, the IAEA began its strengthened safeguards system starting a process leading to the signing of Additional Protocols and eventually to the gradual implementation of integrated safeguards within EU member states.

Implementation of Integrated Safeguards

The Liaison Committee foreseen in the safeguards agreement met with renewed vigor during the course of 2007, and with the prime objective of improving cooperation and creating the conditions necessary for a smooth implementation of integrated safeguards within the EU. Early agreement was reached by the Liaison Committee at Higher Level (HLLC) on the use of a limited number of agency scheduled inspections a few of which would be unannounced. A key early decision was that the principles of NPA would continue to apply and be adapted in order to accommodate new developments.

Frequent meetings of the Liaison Committee at the Lower Level (LLLC) were called in order to agree on the modalities for this. The work of the LLLC focused initially on integrated safeguards in items facilities resulting in agreed integrated safeguards Partnership Approach papers. Early agreement was reached on two guiding principles that greatly facilitated the work of this group:

- the number of unannounced inspections would be kept to a minimum by the use of appropriate technology. The IAEA accepted that they would make use of video surveillance even though their preference was for no permanent installation. Agreement on this latter aspect meant that agency scheduled inspections for unpredictability purposes could take place with sufficient notification so that both organizations could be present from the onset.
- A 'rolling scheme' of agency scheduled inspections would be set up and provided to Euratom on a monthly basis with a three month look-ahead. The scheme would only indicate the scheduling of a short-notice inspection but give no information on the installation, or state concerned. It is worth emphasising, that the scheme does not restrict the agency's potential for unpredictability as this is adequately covered by the provisions relating to complementary access.

An integrated safeguards partnership approach paper has also been agreed for LEU fuel fabrication plants based upon random inspections which provide 100 percent statistical coverage of material flow. Typically four random inspections will be scheduled by Euratom with the IAEA attending on a random basis. At least one such inspection would be scheduled by the agency. In order to plan and implement flow verification using an approach based on random inspections, the operator will provide a regular forecast on the operational program, including planned inventory changes and periods of shutdown. The operational forecast should be prepared at the end of each year, for all receipts and shipments foreseen for the year, and updated during the year as appropriate. The state and operator receive notification of the inspection typically twenty-four hours in advance of the inspection, though under certain plant conditions, inspections with zero notification may be scheduled.

The integrated safeguards partnership approach for enrichment plants is based along similar lines with the agency making full use of Euratom verifications by random participation in Euratom scheduled routine inspections. Agency requirements for unpredictability are facilitated through a limited number (typically three) of limited frequency unannounced access that they will perform alone without advance notification.

Work is currently ongoing on the preparation of partnership approach papers for on-load reactors.

A need has been identified during discussions to draft facility specific papers for more complicated installations and work is progressing on these. Throughout the negotiations, EU member states have been kept fully briefed with tri-lateral discussions taking place as and when necessary.

A key feature of NPA is the cooperation on research and development in order to reduce resource expenditure on both sides. This policy has been strengthened and is reflected in new joint technical support papers.

The work of the LLLC was guided by the HLLC that decided which tasks and which priorities had to be followed and eventually endorsed the agreements. The cooperation on both levels proved to be productive and efficient and all parties involved (IAEA, Commission and EU member states) are looking forward to a successful continuation.

A Revised System of Euratom Safeguards

The European Commission has now reached broad agreement with the Council and other major stakeholders on the implementation of Euratom Treaty safeguards and in doing so, concluded a major review of its work which began in 2001. The resultant new safeguards approach provides for a system of control and verification adapted to today's nuclear environment providing as it does a flexible, risk based approach.

The linchpin of the Commission's work remains the provision of the necessary assurance that nuclear materials are not diverted from their intended use as declared by the users. The purpose of such an assurance is self-evident as is its importance given the resurgence of nuclear power in the EU. That said, this overarching objective is linked to cross-cutting issues affecting several other Commission directorates, international organizations, and third parties:

- A rigorous and effective assurance of use not only provides for confirmation but also acts as a significant deterrent to any misuse. Given the concerns over a range of illegal uses from simple neglect to radiological terrorism this is a key issue.
- It is clear that while all risks must be considered in any rigorous assessment of nonproliferation, those posed by EU member states are not at the forefront of public attention. The same cannot necessarily be said for all third states, some of whom may be tempted to look to the EU as a potential source of illicit fissile material. A control on use under Euratom Treaty safeguards therefore also provides for assurance on an international dimension and provides a solid basis for the verifications of the IAEA—the responsible body for worldwide safeguards.
- Any misuse of nuclear material has the potential for a serious negative impact on energy policy. Public perception of nuclear power would be greatly influenced should such an incident occur, with subsequent implications on security of supply.

Synergies with International Safeguards

In today's world, many of the barriers that prevent free flow of trade and workers have been broken down or removed entirely. Certainly, this long-standing objective has been achieved within the twenty-seven member states of the EU which together account for some 35 percent of world nuclear power production. It would be difficult and certainly less effective for the Commission to base its safeguards assurance upon an assessment of individual member states given the absence of state frontiers. Meaningful Euratom Treaty safeguards require an assessment based upon the entire region.

From an international perspective, the Commission is also responsible, under Article 77 of the Treaty establishing the Euratom Community, for assurance on the peaceful use of nuclear material received from third party states and for provisions under the comprehensive safeguards agreement INFCIRC/193. Member states transfer such responsibilities to the Commission under the provisions of this Treaty. (While this in itself obviates any requirement for individual states to maintain a state system of accounting and control, this does not mean that related national organs are superfluous. Indeed experience has shown the value of national representation in this area especially for the implementation of the additional protocol and similar reporting.) There is and always has been an obvious overlap in the safeguards objectives of Euratom and the IAEA and this has been taken into account during the drafting of the verification agreement and subsequent implementation. The Commission's safeguards system is today considerably more comprehensive in scope resulting in synergies that should be fully used by the IAEA:

- From the IAEA perspective of providing assurances on nonproliferation there is clearly little benefit in safeguarding nuclear material in a weapons state. However, it is recognized that nuclear materials of strategic value have high economic value and concerns over clandestine use dominate related discussions. Euratom safeguards are based upon an assurance of operator use and such assurances in weapon states installations should be taken into account by the IAEA. The IAEA system has evolved over the years and the agency has real and justified concerns over undeclared material. Potential clandestine sources of such material are not limited to NNWS.
- Confirming the absence of undeclared feed and product requires confirmation that declared material is used as declared. Stopping such assurances at borders which are in

many cases virtually non-existent either politically or physically is not logical. Euratom has signed cooperation agreements with a number of states, which provide the framework for obtaining the necessary mutual assurance that shipped material has been securely transferred and properly accounted for even after leaving the EU.

- Euratom inspectors will always make inspections, and the IAEA are welcome to make maximum use of them. Today's technology is such that inspector presence is not required in order to obtain independent conclusions.
- Euratom safeguards inspectors work in close cooperation with the Joint Research Centre (JRC) on numerous related technical projects. The JRC continues its contribution to safeguards effectiveness including support to the IAEA with new methods and approaches[5] and due account should be taken of this. The EU on-site laboratories provide a good example of such cooperation with EU laboratories in reprocessing plants used by the IAEA as the model for Japan.
- Audits of operator NMAC systems have been strengthened and legislation drafted in order to define best practice in this area. The assurance provided by such audits is qualitative and cannot in itself provide any guarantee on the presence of material. However, the need for high-quality NMAC systems is widely recognized as are the benefits the Euratom verifications bring about.

The Longer Term

A strong comprehensive regional safeguards system in the EU, adequately equipped with modern technology, may have direct consequences, in particular under Integrated Safeguards, that should in the future be reflected by lower in-field requirements on the part of the IAEA without a loss of conclusiveness for international safeguards. Where direct verification is required, this should be done using modern fully authenticated systems that do not necessarily require inspector presence. In essence, the agency's role would be more related to data treatment and analysis at headquarters rather than in the field.

There is a political will within the EU member states to maintain a strong system of Euratom safeguards, and to see limited agency resources being used where there is most need. Safeguards today, allows for a system of differentiation between states which should not be seen as discrimination. The IAEA should make maximum use of any strong and effective system of regional safeguards.

Conclusion

The Commission places high importance in a continued excellent cooperation with the IAEA, no more so, than in the field of safeguards and in particular during the implementation of integrated safeguards in the EU. The Commission understands and fully accepts the need for the IAEA to draw its own independent conclusions. The partnership approach between the two inspectorates provides a powerful mechanism which should enable the agency to make significant savings within the EU. Technology already has the solutions that would enable the IAEA to use data obtained from effectively authenticated non-destructive assay and surveillance systems. It appears that there is great scope in taking advantage of these possibilities, allowing the agency to focus on priority areas of safeguards. In a system based on "broader conclusions" and qualitative assessment, it is noted that the agency could make much more use of the information available from Euratom's well established regional system.

Changes to the IAEA approach towards regional safeguards bodies like Euratom would require a new mindset in the agency. Euratom on the other hand would have to accept that the agency could decide and advise on what it needs in order to take advantage of their possibilities. In addition the agency should evaluate the efficiency and effectiveness of other regional systems in order to avail itself of similar savings.

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Richard Clarke is a nuclear engineer. He joined the European Commission as a safeguards inspector in 1991. From 2004 to 2008 he worked in the area of nuclear safety and decommissioning, in the Nuclear Energy directorate. Back in Safeguards 2007, he became head of the sector for conception, planning and evaluation of inspections.

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The Challenges of Nonproliferation Information Analysis

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Information analysis is an activity that is being conducted by all living beings, beyond humankind, in order just to survive. One collects, processes, evaluates, consolidates with other information, compares with previous knowledge or instinct, explores other scenarios, and finally decides on a course of action. Unfortunately, every single step of the way has its own risks that can possibly lead to what may appear to be the wrong decision.

When individual human factors come into the picture, information may become power, bad news may have to be avoided, communication breakdown often occurs, and private agendas can overshadow general interest. Modern proliferation challenges require addressing all the pitfalls by which information can be used ineffectively or misused. Unfortunately, these proliferation challenges can also benefit from diverging political agendas, bureaucratic rigidities, the attractiveness of money, and globalization.

For the International Atomic Energy Agency (IAEA) to remain the sustainable provider of credible information and safeguards conclusions to the international community with regard to the assessment of existing and future proliferation risks, the establishment of appropriate resources including adequate computer support and the overall optimization of internal processes is a must. As is traditional, assistance in all relevant areas must come from member states but we also need to consider support from other sources in order to address the critical areas for improvement at a faster pace.

Based on ongoing experiences in dealing with information analysis related to nuclear proliferation issues, this article provides food for thought with a broad view of the challenges that are faced and emphasizes concrete ideas to ensure that the proliferation community remains fit to address these challenges for the future.

Information: The Most Difficult Raw Material to Process

In order to properly understand a process, it is essential to make sure that the materials that are being processed are also well understood. For instance, in a chemical process doesn't it logically apply that the safe handling of these chemicals requires a fundamental and basic understanding of the various compounds involved? What reactant is needed to make a certain product from the ore to its final use? Is the material pyrophoric and should the presence of oxygen be avoided under certain conditions?

Information requires a similar understanding of the process. As I highlighted in my 2007 *JNMM* article,[1] attention has to be dedicated to the nature of information: are we dealing with raw data, validated information, or real knowledge? Collecting the data relevant to safeguards and nuclear proliferation is not enough, although accessibility always remains a key limitation. The characteristic of data is that rarely do they represent information unless some effort, sometimes significant, is involved. An important parameter for turning data into information is the necessity to have them processed by adequate expertise and experience (the right reactant) and to avoid handling them in a manner that can turn counterproductive (oxygen in the presence of hot uranium!).

Unfortunately, there are no standards for handling information according to best practices. Will one day the International Standards Organization (ISO) produce a standard for information analysis? It's doubtful. Information analysis and dissemination is very specific to the area of work. The exchange of medical information circulating between doctors in a complex case before a life-saving operation may not involve the same methods as information flowing between inspection and satellite imagery analysis teams.

In general, heritage such as the traditional one-way flow of information, preventing essential feedback, or ill-understood information security requirements ("Need to know" exploited as "Need to hide") can lead to major drawbacks, including the fact that essential pieces of information may be missed, inappropriate knowledge generated, or ineffective actions taken.

To effectively address the challenges we face today, the safeguards and nonproliferation relevant communities must move out of the legacy of separated information silos and optimise the analysis and dissemination of information so that the identification of early warning indicators enhance the ability of the system to prevent rather than just *respond* to particular crises.

Sources to be Developed

While the credibility of assessing proliferation threats is at stake, be it for drawing of conclusions on states with respect to their safeguards obligations as the International Atomic Energy Agency (IAEA or the agency) is mandated, the paramount focus is to obtain as many relevant pieces of information as possible. With regard to raw data, the IAEA collects it from three different mechanisms:

- State declared information from member states and information gathered from in-field activities such as inspectors' observations or remote monitoring data, all resulting from

the safeguards agreements between the agency and its member states;
- Open sources, including commercial satellite imagery, obtained through locally developed methodologies aimed at collecting information freely available to anyone or through commercial contracts with information providers, such as libraries;
- Information voluntarily provided by states and other entities, such as commercial companies.

The international security world is made today of different pieces that have not explored well enough the needed synergies to "remain ahead of the game" with threats, including the terrorists' threats, which have been growing. At least, from the perspective of funding, governance, and information circulation components such as safeguards, security, export controls, and national defense systems have not yet come with a *modus operandi* that would allow nonproliferation counter measures to be commensurate with such developing threats. Systems can sometimes align towards a common objective when a crisis has exploded and needs to be resolved (a good example is when the agency, with the support of sometimes "unusual players," managed to successfully perform its UN Security Council mandate in the 1990s to address the Iraq situation). However, much can be done in a more comprehensive manner and the identification of emerging threats can be collectively addressed for developing crises before they erupt.

An example of areas where tremendous progress remains to be done as far as existing but improperly exploited data, is with trade related information and the consequences of globalization. The coming out or opening up of Libya was an important trigger: the discovery of the significance of covert trade networks where non-state actors become major contributors to proliferation and allow proliferation candidates, possibly non-state entities, to contemplate moving forward while lacking the overall infrastructure to do it indigenously. Some legal instruments have been established (e.g., UNSC Resolution 1540), but little has been done to actually facilitate the circulation of relevant trade information within the safeguards community, including towards the agency. When will it be acceptable for the Model Additional Protocol (INFCIRC 540) annexes to be revised or even simply updated? How much effort will the agency need to spend to obtain significant trade-related information from proliferation-conscious companies, along the line of its proposed outreach program?[2]

Another obvious area of needed improvement is actually associated with the natural and welcome dissemination of knowledge, directly linked to the progress in humanity. Nothing can prevent the dissemination of education and technological development for good reasons, capabilities, intellectual and practical, that may have an impact in generating proliferation risks that were previously unlikely. Declassification, publications of information previously considered sensitive, and the ability to buy off-the-shelves items previously reserved to a limited community (biggest examples are, of course, computers) add to the fertilization of proliferation threats. Wouldn't it be the time to reflect on what can be done to ensure that progress is not intimately associated to self-destruction through increase of the nuclear proliferation risks? How can the agency become fitter to address such risk? One could imagine that, at a time when nuclear renaissance is an attractive commercial prospect, some sponsors could come out and support such efforts.

The Role of the Individual

The value of the collection of raw data and the extraction, out of the background noise, of the signals that matter fundamentally rely on the quality of the sensors implemented. Sensors, be they the eyes of an inspector, the laboratory instrument used to analyze an environmental sample or the remote sensing technology embarked on a satellite can only deliver what they have been made to do. The effectiveness of the collection can only be the result of the appropriate combination between intrinsic skills and "especially designed" features.

For information and human beings, the "especially design" aspect can be seen as the result of training. But can one be trained on anything? No way! Anyone who has ever participated in a search and rescue operation after an avalanche and seen how a well-organized team of twenty people can waste precious time until the avalanche rescue dog finds the unfortunate skiers within seconds of his arrival at the location can only realize that training followed by well-structured approaches cannot compete with natural skills. And the superiority of one race over another has no place when big things such as life or death are at stake. Actually, if the team of humans had been made of Nobel Prize winners and Olympic champions, the result would have been no different.

One of the fundamental mistakes that is often made with regard to analysis of information is the fact that anyone can be trained and perform as an analyst, and also be expected to find the clues that will allow identification of follow up actions and the drawing of credible conclusions. The first characteristic that should be sought for an analyst might be an innate gift to be inquisitive or an analyst by nature, as well as having the motivation to perform as an analyst. It is interesting to observe that anyone will agree to such a concept for physical performance: what are the chances that a shot put competitor would also be a marathon runner? In the realm of analysis and the specificities of analytical skills, particularly in the nuclear nonproliferation area, it seems that even bright spirited individuals may be ready to ignore such evidence. It may come from the fact that anyone has to perform a bit of analysis for every single action we may encounter in life. But how many of the decisions that we make in life have been the wrong ones? Let's not even talk about investments before this time of economical crisis. But even more relevant, when born in the right part of society, we can all read and write, yet what proportion of us can make a living out of writing novels and essays? Probably a proportion equivalent to those of us who can be fine nonproliferation analysts.

The topics relevant to nuclear proliferation are so broad that we will always be dramatically short of the proper knowledge. The nuclear engineer, the political scientist, and the lawyer, all have a very narrow view of their proliferation world. At the same time, fighting proliferation needs the technical, political, and legal understanding to cope with existing and developing issues. We even may need more focus on cultural framework and psychological issues. And why not engage more professional investigators like police and customs officers? What about a psychologist or an historian?

In the technical arena alone, addressing proliferation issues requires a knowledge that covers a very broad number of scientific and technological disciplines. Will someone qualified as an "enrichment expert" have the same level of reliability for the assessment of a centrifuge, laser, or chemical enrichment program? Certainly not!

Actually, the generalist has to play a fundamental role in the overall assessment, as he will have the broadest view and the best understanding of the context of an issue. Even better than the generalist, the IT world concept of "versatilist," (i.e., an individual applying depth of skill to a progressively widening scope of situations and experiences, gaining new competencies, building relationships, and assuming new roles) should be a mandatory asset on any analytical or verification team. Do we have in place the right education, training curriculum and on the job training to develop and grow versatilists?

However, such a role on each analytical project has to start with an essential assessment: understanding the limit of his/her knowledge in every single area that matters in a case. What is more risky than the "know-it-all" who genuinely does not realize his own limitations? First steps should lead to the identification of the right composition of a team, in other words filling the gaps with specialised resources that will only be capable to provide sustainable assessment. Consequently, at this time, when the experts of the past are retiring, when new technologies appear with proliferation potential, when approaches to safeguards and nonproliferation has to improve, will our community, the agency and beyond, be capable to gather a network of advanced expertise that can tackle the future needs and challenges?

Instinct, opinions, and gut feelings are important assets that always come with experience (the opinionated beginner may actually not be a particularly promising analyst!) and enable us to cut the time and effort needed to develop a full blown evaluation process. That is why seasoned analysts are invaluable resources in analytical teams, as we evolve in an environment that always lacks resources. However, one of the biggest possible mistakes is to rely too heavily on shortcuts, when an experienced individual takes an unchallenged lead and attempts to singularly justify processes and conclusions, as an individual alone may often fall into a self defined mind trap.

It is difficult to talk about expertise without mentioning the issue posed by the world of alleged or self-defined nonproliferation specialists who may surf on a reputation simply based on the fact that it is a field where it is too easy to know a little more in some areas than your counterpart and appear to be knowledgeable simply because "in the kingdom of the blind, the one-eye man is king." Having lived through news reports and other discussions on headline topics, it sometimes looks as if we are evolving in a world where the blind man who speaks forcefully may be seen as the king, at least temporarily, until demonstrated wrong by the facts.

The Limitations of the Processes

One of the main components of analysis is communication, i.e., the process of transfer of information between one entity and another, persons, offices, organizations, communities, countries, etc. Transfer of information cannot be seen outside of its local context, and in particular the consequences for the individual holder.

The first drawback often observed is the "information is power" syndrome. Many get the feeling that keeping the information for themselves may have an advantage for their own profit (e.g., "I'll break the news myself to the boss, so that he knows it comes from me."). The "need to know" culture, essential in a world where classified information is abundant (starting with the very specific responsibility of the agency coming from the fact that states have entrusted it to be the custodian of sensitive information provided through declarations and field access), is often the excuse to validate dangerous behaviour in terms of information non-dissemination. Why dangerous? What is the point of conducting all-source analysis to draw credible conclusions while key elements of information are hidden from those deriving them? Would the oncologist be deprived of blood test results because the laboratory belongs to another hospital?

The concept of moving from a "need to know" to a "need to share" culture has hopefully percolated within the security sphere, particularly after 9/11. How long will we need to wait for the safeguards and nuclear nonproliferation communities to adopt such a concept? Do we also need a catastrophic event to wake up?

Another danger, when information is actually disseminated, is the risk of bias. Bias certainly starts with the personal view of the individual analyst, a personal view that may be misleading by an expertise limitation, as highlighted earlier. But biases can be introduced purely for private interest (better please the boss by confirming his already strong opinion than being the bearer of bad news, e.g., "facts and proper technical assessment" disagree with your boss), organizational political agendas (selecting the data that fit the expected conclusion), or practical needs (need to maintain a good enough level of interaction with a counterpart). The most risky consequence of individual bias is when the conclusion drawn by an organization is essentially that of an individual who read the perceived expectation of the system, designed an analytical process, and artificially disseminated information that fits with such expectations, based in particular on the limited knowledge of his environment.

The only safe way out of this path is by ensuring that processes put in place suppress the risk of "stove piping" through the systematic and constructive interference of individuals or entities with obviously different perspectives. Differences in points of view and conclusions are essential for the determination of the highest level of assurance associated with a conclusion. It was, for instance, a fundamental quality assurance mechanism that in the early years of the implementation of the IAEA UNSC resolution 687 mandate, UNSCOM was systematically (even if most often unfairly) critical of anything the agency was doing. The agency had to integrate other points of views that ultimately led to a quasi-perfect assessment of Iraq's past program and remaining capabilities.

Another never-ending challenge is determining when enough is enough. As the agency's endeavour is essentially committing itself to a conclusion that guarantees the absence of diversion or absence of undeclared activities and materials, when is that doable, while the absence of evidence cannot be equated to the evidence of absence? And because resources are limited, what priority for which project? Actually, a fundamental tool is being able to determine the coherence or consistency of all information available.[1] The trickiest part of such an approach remains the gap analysis and the limited trust we may have in having the ability to collect or be provided with the right information. Aren't we back to the first collection challenge: Will we be able to access that significant part of relevant information which has not been traditionally reached by the safeguards community?

Rendering all information available to those who need to have it and focusing such information in a manner that supports knowledge generation and preservation for supporting actions that need to be carried out has to be the main objective of information management within organizations like the IAEA. Unfortunately, an adequate computer environment will never be more than an enabling platform that will allow access and proper information dissemination. This assumes that first, the right information reaches the organization, and second, recipients behave systematically and comprehensively understanding their responsibility to share, for the survival of the overall credibility of the organization.

Conclusion

The legal basis for safeguards has not evolved since the 1997 timeframe and the adoption of the Model Additional Protocol. This is despite the recognition of the growing proliferation threats such as the possible role of covert trade and the globalisation of technologies and knowledge. We urgently need to reflect on ways to reinforce the IAEA's verification system and take action on implementing more practical means.

The first imperative direction is to make sure that in its endeavour to "draw credible conclusions" the agency is provided, from the community which supports it but also from usually more distant arenas, with all relevant information that matters to understand the nuclear proliferation landscape and proliferation developing risks. As importantly, improving current nonproliferation analytical processes, wherever they are conducted, remains an essential route to maintain the level of credibility established by past achievements.

As resources will inevitably be one of the most limiting factors for the activities conducted in an organization like the IAEA, it is fundamental that motivated supporters dedicate more thought, and later resources in the form of funding, information provision mechanisms, expert education and assistance in tools supporting improved processes to strengthen the ability of our community to address current and upcoming proliferation challenges.

End Notes

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Safeguards Information from Open Sources

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Abstract

The recent explosion of open-source information and the availability of advanced tools for collecting, mining, and analyzing such information have enhanced the role of open-source analysis in safeguards and nonproliferation studies. This paper discusses the role of open-source information in analyzing potential proliferation pathways, including diversion of declared nuclear material and the potential detection of undeclared nuclear activities. We see an evolution of integrating such analysis into on-site inspections and assistance in prioritizing aspects of the state evaluation process. Open-source analysis is unlikely by itself to provide a definitive detection of clandestine activity. However, it may contribute to identifying locations, institutions, people, and activities that should be targeted for further investigation and may provide important additional details that add perspective on the relevant technical, industrial, and military capabilities, as well as R&D activities, of a particular entity or group. We discuss why open-source analysis has become, and continues to be, a valuable nonproliferation asset, as well as some of the limitations and needs for additional capabilities.

Introduction

The recent explosion of open-source information and the availability of advanced tools for collecting, mining, and analyzing such information have enhanced the role of open-source analysis in safeguards and nonproliferation studies. In some cases, open-source analysis can provide the first clue that a state might be pursuing a nuclear weapons program counter to its treaty obligations and public declarations. Open sources may provide clues to specific locations for the application of more-detailed technologies (imagery, environmental sampling [ES], on-site inspections, etc.). Open sources are often used to research and identify relationships between entities (individuals, organizations/corporations, locations, etc.) that may then warrant additional investigation.

Open sources include all information generally available to the public. Basic open-source analysis resembles traditional research as conducted by scholars, economic analysts, or legal investigators. National intelligence agencies, law enforcement organizations, nongovernmental organizations (NGOs), and international treaty-monitoring entities such as the International Atomic Energy Agency (IAEA) also carefully examine a broad range of open-source information to meet their needs.

Open sources typically include the following:

- Publicly available information, such as that provided by the news media (e.g., investigative journalism), governments (e.g., policy statements, speech transcripts), commercial companies, and NGOs. Much of this information can usually be found on the Internet.
- "Fee-based" information, such as that found in published scientific and technical literature or subscription databases
- Information that is normally made available only on request or to specific individuals. Such sources include the following:
  - Company financial reports
  - Conference information (participant lists or paper titles, abstracts, or full text)
  - Internal publications of various organizations
  - Internal travel reports
  - Internal databases open to member entities, such as IAEA Technical Cooperation summaries or IAEA International Nuclear Information System (INIS)
  - Unpublished scientific papers
  - Patent applications
- Information that is both fee-based and available by specific request, such as satellite imagery, which is made available by a private vendor, such as DigitalGlobe.

Open sources do not include information that is legally protected, classified, or restricted in distribution (unless it becomes available to the public by some means, in which case it requires particularly careful validation by independent sources).

To perform its core responsibilities, the IAEA collects, evaluates, analyzes, and disseminates open-source information as part of its current nonproliferation assessment activities and therefore provides a good example of open-source use. Characterized as the "world's nuclear watchdog," the IAEA has two primary safeguards-related responsibilities: providing the international community with assurances that Treaty for the Nonproliferation of Nuclear Weapons (NPT) member states are not engaged in the diversion of *declared* nuclear materials and investigating and responding to indications of *undeclared* nuclear materials, facilities, or activities, which could be a violation of a state's safeguards obligation.

In the next section, we discuss the recent history of safeguard challenges, challenges that ultimately guided the IAEA's Department of Safeguards toward the incorporation of open-source information into its assessment processes.

Evolution of Safeguards during the 1990s

In April 1971, the IAEA Board of Governors approved the model text[1] for agreements for the application of agency safeguards in connection with the NPT. Under these comprehensive safeguards agreements (CSAs), the IAEA has the right and obligation to ensure that safeguards will be applied on "*all* source or special fissionable material in *all* peaceful nuclear activities within the territory of the state, under its jurisdiction or carried out under its control anywhere" [emphasis added]. As implemented in practice, and until the uncovering of Iraq's *undeclared* nuclear program in 1991, IAEA safeguards focused on ensuring that declared nuclear materials were not diverted from peaceful use.

The IAEA Secretariat had reasons to believe it lacked a real political mandate to investigate indications of undeclared nuclear activities. Before 1991, the Cold War powers did not look to the IAEA to pursue leads about suspected clandestine nuclear programs in NPT signatory states. Much of the nonproliferation attention during that period was focused on slowing or reversing the non-safeguarded nuclear weapon development programs of states that were not NPT signatories. When NPT member states discovered specific indications of noncompliant nuclear activities in NPT states, those leads generally were not brought to the IAEA for action, but rather were dealt with through quiet—if sometimes coercive—diplomacy or through other means, such as interdiction of supply.

- In 1988, for example, media reports alleged that Taiwan, China, in the face of strong bilateral diplomatic pressure, had halted construction of an undeclared nuclear facility.[2] There were no reports of IAEA involvement in investigating this allegation.[3]
- In the period before Iraq's August 1990 invasion of Kuwait, it appears that some member states already had acquired information pointing to the existence of undeclared nuclear activities in Iraq, most notably a gas-centrifuge enrichment effort, which the member states did not bring to the IAEA for action. In July 1990, for example, customs officials in Frankfurt intercepted nearly 1,000 maraging steel forgings, intended for the manufacture of gas-centrifuge components, en route from another European country to Iraq.[4] Iraqi procurement of these items in such large quantities would seem unlikely unless experiments with nuclear material at the single-machine or small cascade level already had been conducted, and thus would have been a fairly strong indicator of incomplete nuclear material reporting on Iraq's part.

The attitudes of the IAEA and its member states about whether, and how, the IAEA should concern itself with undeclared nuclear activities was transformed in light of 1991–1993 revelations concerning clandestine nuclear programs in NPT member states. Note the role of satellite imagery described in the following sections (such imagery was provided by member states during the early 1990s, but comparable resolution became available commercially toward the end of the decade).

Iraq

Even though it was conducted under special authorities conferred by UN Security Council Resolution (UNSCR) 687 and later resolutions, the IAEA's investigation of Iraq's nuclear program after the first Gulf War had a profound impact on the NPT safeguards system. Not only was this the first time that a safeguards violation was reported to the Security Council, it also drove a political consensus to strengthen safeguards against undeclared nuclear materials and activities.

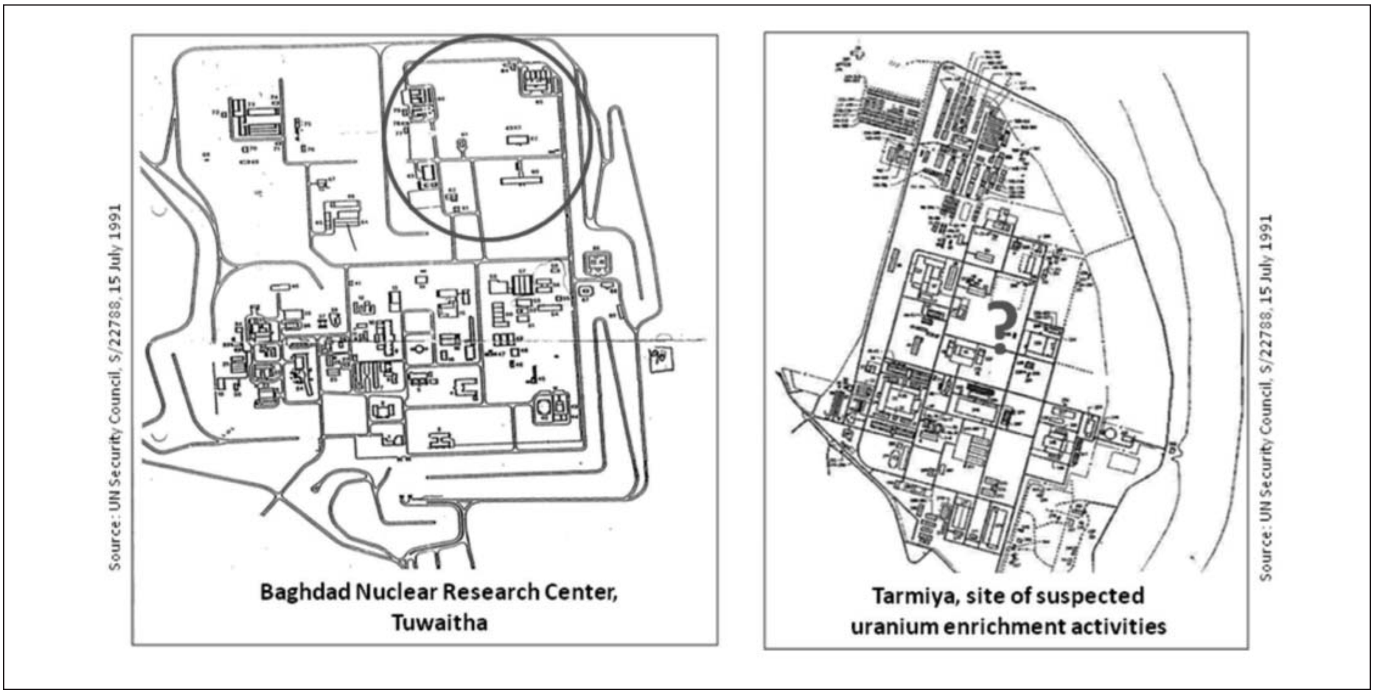
Iraq also was a training ground for individuals who would go on to lead the IAEA's investigation of undeclared nuclear programs in other cases, and it served indirectly as a test bed for new tools and approaches, many of which later would find application in NPT safeguards. Examples include the following:

- Short-notice inspection at undeclared locations
- Environmental sampling, including mass spectrometry on an individual particle basis
- Nuclear material measurements in unusual configurations in an unpredictable field environment
- Use of third-party information, including information from member-state intelligence services, to include satellite imagery
- Use of specialized technical experts to augment the agency's existing staff
- Integrated, systematic evaluation of a state's nuclear program

While the first priority of the IAEA's initial May 1991 UNSCR 687 inspection team was to locate and secure the high-enriched uranium fuel at the Baghdad Nuclear Research Center, Tuwaitha, the team also was advised by a member state to look for evidence of uranium enrichment work, both in a newly constructed area of Tuwaitha and at a large facility north of Baghdad, designated Al-Tarmiyah. The team was shown *overhead images* of these sites and was also provided with detailed line drawings of these sites,[5] with every building indicated and numbered, looking much like the site maps that states today provide the IAEA under Article 2.a.(iii) of the Additional Protocol and that are now verified with commercial satellite imagery.

The May 1991 inspection turned up some potential evidence of an electromagnetic isotope separation (EMIS) program, but a defector soon provided a much more detailed picture and additional leads. In June 1991, exploiting actionable leads from member states concerning locations where equipment from this undeclared program was being concealed, members of the second inspection team were able to obtain photographic evidence.

Figure 1. Use of member state information and overhead imagery as an inspection tool in Iraq. Undeclared sites, previously unknown to the IAEA, were discovered and included one adjacent to a declared site.[6]



Beyond the EMIS program, the Iraq inspections gave the IAEA important experience in investigating a gas-centrifuge enrichment program. Member state experts were recruited to augment the IAEA's ability to verify activities in this area.

The IAEA's Iraq mandate also extended to investigating and eliminating Iraq's nuclear weaponization program. Acting on a lead from a member state, the IAEA obtained detailed internal progress reports and other explicit documentation concerning Iraq's efforts to design, develop, and manufacture nuclear weapons. Experts from the nuclear weapons states assisted the IAEA in its evaluation, being careful of course to observe the requirements of their own national laws regarding protection of sensitive information from disclosure to the unauthorized individuals.

Iraq was a wake-up call for the IAEA's safeguards system. Director General Blix, in remarks to the United Nations Security Council (UNSC), said that for the IAEA to be effective against undeclared activities, three elements were essential:

- *Information.* The extent to which the IAEA is aware of the nature and locations of states' nuclear and nuclear-related activities
- *Access.* The extent to which IAEA inspectors have physical access to relevant locations, as well as technical means to exploit such access
- *Political will.* The will of the international community, through the UNSC, to take action against states that are not complying with their safeguards commitments

The Board of Governors affirmed the agency's right to use all available information and affirmed that NPT safeguards apply to all nuclear material that *should* have been declared, not just to material reported by the state. It reaffirmed the right to conduct special inspections, and it called for earlier notification of nuclear facility design information. The UNSC declared the proliferation of nuclear weapons and other weapons of mass destruction a "threat to international peace and security" under Chapter 7 of the United Nations Charter and declared that in cases where the IAEA notified the UNSC of violations, the Security Council would "take appropriate measures."

North Korea, 1992–1993

The nearly concurrent case of North Korea presented an opportunity for the IAEA to apply lessons and methods from Iraq, and it also reinforced the importance of access to undeclared locations.

In 1992, North Korea brought into force its NPT safeguards agreement and submitted its initial report to the IAEA. The IAEA and member states were pleased that the declaration included previously secret nuclear facilities at Yongbyon, among them a uranium conversion and fuel fabrication plant, a 5-MWe gas-graphite reactor, and a reprocessing plant. Some member states suspected, however, that the Democratic People's Republic of Korea (DPRK) already had discharged and reprocessed up to a full core of spent fuel from the gas-graphite reactor, activities that were not declared in the initial report, which declared that only gram quantities of plutonium from a few tens of failed fuel rods had been reprocessed.

Figure 2. Imagery of DPRK showing Building 500 and an undeclared waste storage area[7]

The IAEA collected swipe samples at the reprocessing plant, and analysis of these samples was not consistent with the DPRK declaration. Acting on the basis of *satellite imagery* provided by a member state, the IAEA requested access to two undeclared locations, including "Building 500," a building near the reprocessing plant where it appeared North Korea may have hidden high-level waste, a by-product of reprocessing. DPRK officials permitted only a very limited visit to the site, which it said was a military facility unrelated to the reprocessing plant.

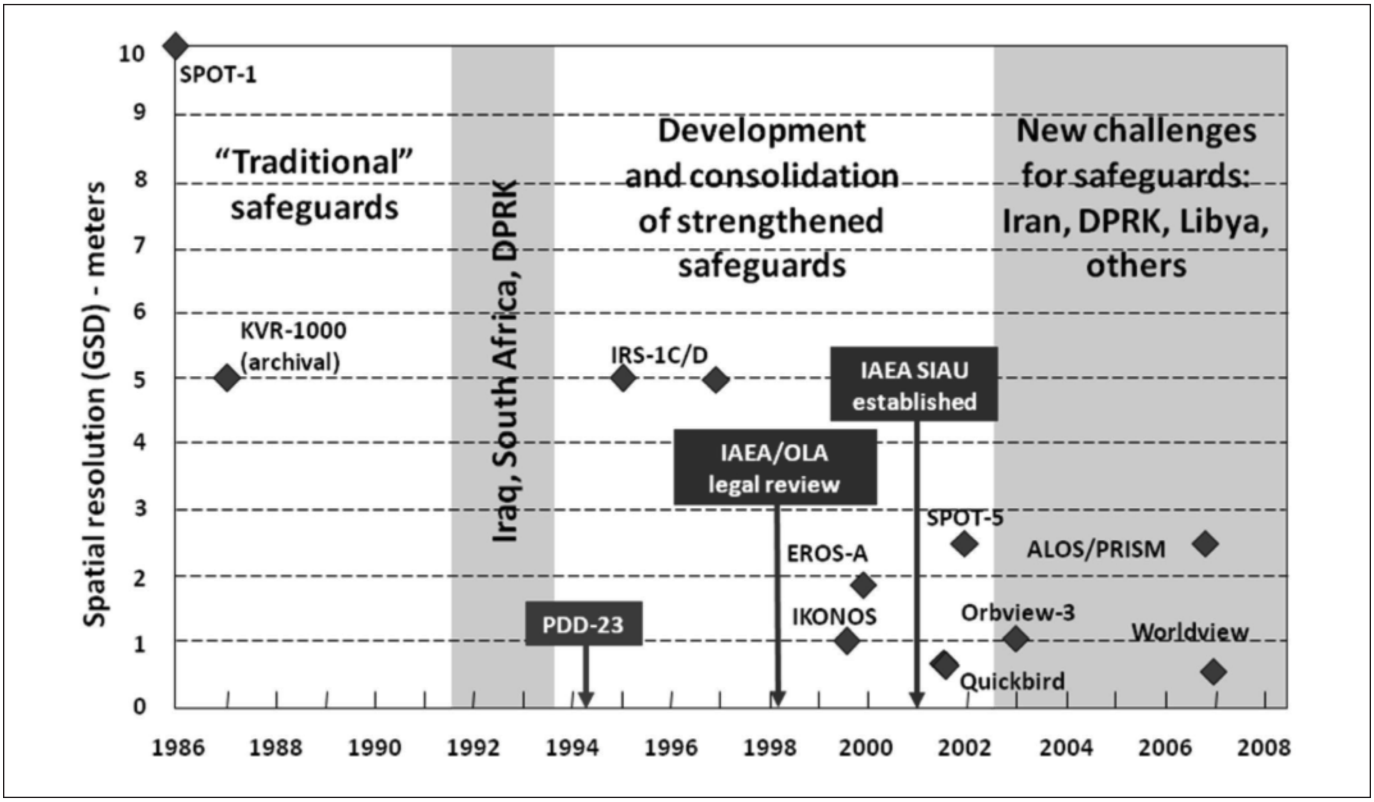
Recognizing how important a more-thorough technical investigation of the suspect waste sites would be for the IAEA's ability to resolve the inconsistencies in the DPRK reprocessing declaration, the Director General asked the Board to declare, as provided in the NPT safeguards agreement, that access to the suspected waste sites was "essential and urgent" and that the DPRK should comply promptly with the request. It is notable that in his briefing to the Board, the Director General made use of member-state *intelligence satellite photographs* of the sites in question and that both the Director General and the Board accepted its use as evidence in the decision to demand an urgent special inspection.

When North Korea still refused to cooperate with the board's demand, the Director General reported its noncompliance to the Security Council, which called on the DPRK to comply immediately. Although the Security Council condemned the DPRK's lack of cooperation, it could not reach agreement on an action sufficient to compel the DPRK to comply. In 1994, the United States and North Korea negotiated a special agreement, the Agreed Framework, to freeze nuclear facilities at Yongbyon under IAEA monitoring.

Consolidating and Institutionalizing Strengthened Safeguards

By late 1993, the cumulative experience that the IAEA had gained in such a short and intensive period in three cases—Iraq, North Korea, and South Africa—together with the post-Cold War enthusiasm for strengthening the nonproliferation regime in general, provided a strong starting point for implementing improve-

Figure 3. High-resolution satellite imagery became commercially available at just the right time for strengthened safeguards[8]



ments to the NPT safeguards system to provide greater assurance against undeclared nuclear programs.

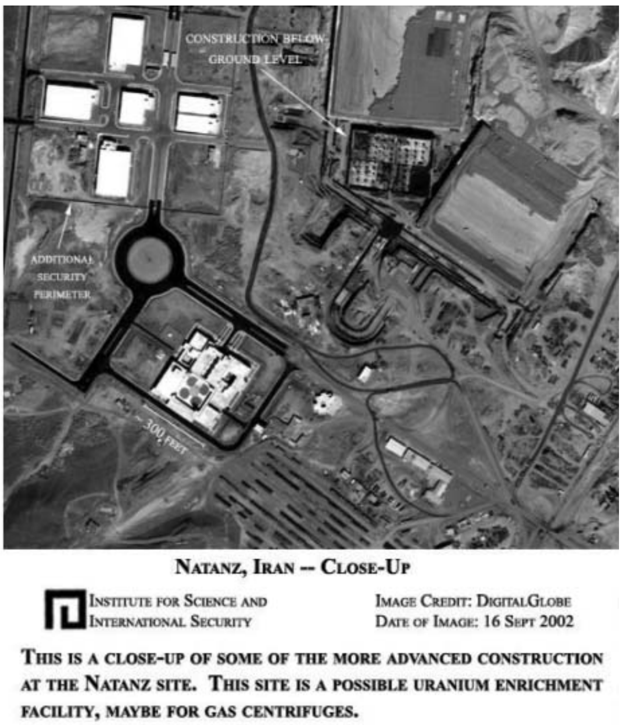
In June 1993, the Board of Governors reviewed a series of recommendations contained in an April 1993 report by the Standing Advisory Board on Safeguards Implementation (SAGSI) on potential measures for strengthening the effectiveness and efficiency of safeguards, and it asked the Secretariat to develop concrete proposals. In December, the Secretariat presented an initial report and announced a two-year project, "Program 93+2," whose aim was to evaluate and recommend specific new measures and present its findings before the 1995 NPT Extension Conference.

As research, field trials, and analysis under Program 93+2 proceeded, and as the board reviewed its progress, it became clear that the recommendations that were beginning to emerge fell into two categories: those that could be implemented already under the IAEA's existing legal authorities (i.e., the Statute of the IAEA and INFCIRC/153) and those for which it appeared additional legal authority would be a prerequisite. In 1995, the Board authorized implementation of measures in the first category, so-called "Part 1" strengthened-safeguards measures, including early provision of design information, improved information analysis, and environmental sampling, among others. Work also began on developing and negotiating model text for a new protocol additional to existing NPT safeguards agreements that would provide the legal basis for the "Part II" measures. The model text was approved by the Board in 1997 and published as INFCIRC/540. The Additional Protocol gave the IAEA access to a broader range of information from the state, including nuclear fuel cycle activities not involving nuclear material, and broader access to locations, including anywhere on the site of a nuclear facility and, for the purpose of environmental sampling, any location in the state.

Another notable development later in the 1990s was the emergence of commercially operated satellite imagery systems providing sufficiently good spatial resolution—on the order of one meter—to be of practical value for IAEA safeguards. The IAEA conducted a careful review of the legal issues involved, and a satellite imagery laboratory was set up to evaluate how commercial satellite imagery could be used. In 1999, the first one-meter-resolution commercial imaging satellite began operating, soon to be followed by other systems, and in 2001 the IAEA formally established a Satellite Imagery Analysis Unit.

Like environmental swipe sample analysis, commercial satellite imagery provided the IAEA with an independent source of information of a kind that once had been available to it only from member states, based on their national technical monitoring capabilities. This has been an especially useful enhancement, in many cases giving the IAEA a means to independently assess or confirm the reliability of information obtained from third parties about alleged undeclared nuclear facilities and activities, as well as

Figure 4. An NCRI 2002 revelation led to confirmation of Natanz as an undeclared uranium enrichment facility in Iran.



giving it a new means to monitor developments at critical sites and an aid to inspection planning.

The best-publicized wake-up call for the value of third-party information (revealed through open sources) and commercial satellite imagery came in 2002. On August 14, 2002, the Foreign Affairs Committee of the National Council of Resistance of Iran (NCRI) held a press conference in Washington, D.C., during which it alleged that Iran was involved in a clandestine uranium enrichment program. Subsequent satellite imagery confirmed the construction of large buried facilities in Natanz, leading to an extensive period of investigation of a clandestine Iranian nuclear material production program. Over the next few years, the NCRI continued to reveal information about the clandestine Iranian nuclear program. Subsequent IAEA validation of that information through independent inspections, open-source analysis, and satellite imagery eventually uncovered undeclared activities in centrifuge uranium enrichment, uranium laser isotope separation, heavy water production, construction of a heavy water reactor, and imports of undeclared material and export controlled articles.

In 2004, the usefulness of IAEA open-source analysis was demonstrated in at least two cases. First, the IAEA investigated South Korean publications that addressed stable-isotope atomic vapor laser isotope separation, leading to the South Korea's reporting of enrichment experiments and its cooperation in resolving the issue.[9] Second, the IAEA investigated publications that suggested the possible existence in Egypt of unreported nuclear material, activities, and facilities related to uranium conversion and reprocessing. Subsequent discussions and inspections in late 2004 and early 2005 led to Egypt's cooperation in resolving these issues.[10]

The State Evaluation Process

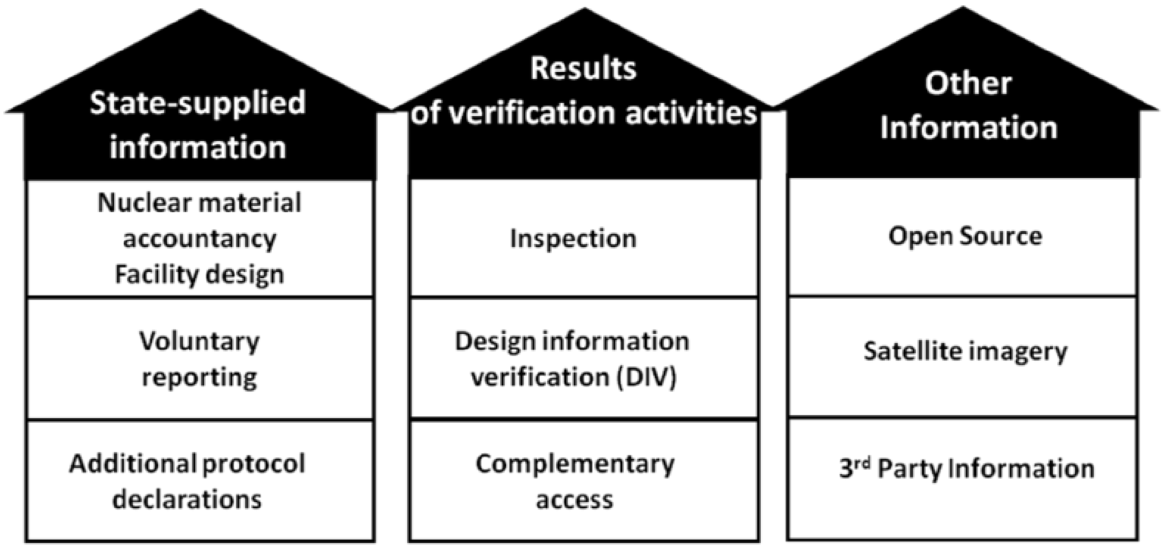
In order to integrate information that has become available from the expanded toolkit of strengthened safeguards, the IAEA has developed the state Evaluation Process (SEP)—a process through which the agency derives, documents, and reviews the basis for its safeguards conclusions and develops inputs to the State-level Approach (SLA) and the Annual Implementation Plan (AIP) for the State for the upcoming year. Simply put, the SEP involves comparing what the state declares its nuclear program to be with information the IAEA collects, verifies, discovers, and confirms about the state's nuclear program. The evaluation determines the extent to which the declaration and other information agree. The objective was to design a safeguards system that includes verification of the correctness and *completeness* of states' nuclear material declarations in order to provide credible assurances of the non-diversion of nuclear material from declared activities *and* of the absence of undeclared nuclear activities. This objective is achieved through a combination of increased nuclear transparency on the part of states, expanded physical access for agency inspectors, new technical measures, and open-source information collections coupled with an information evaluation process in which states' declarations are continuously compared with all information available to the agency.

Information for analysis is gathered in several ways: (1) provided by states according to the provisions of their safeguards agreements and an Additional Protocol (if it is in force) and provided voluntarily, (2) collected by the agency through activities carried out in a state, for example, inspections, design information verification activities, and complementary access activities, (3) collected from open sources and other sources available to the IAEA, and (4) provided by third parties. The open-source collections are extensive, containing scientific and technical literature, news media (including news service databases), country-specific websites, and/or commercial satellite imagery.

Although a single analyst may be tasked with managing the State Evaluation Report for a single state, there are multiple contributors to the product who are expected to reconcile the aforementioned information to affirm the correctness and completeness of a state's declaration. When open-source information suggests that an inconsistency or anomaly exists, appropriate personnel conduct additional analyses, which may include a request for information from the state itself. Unresolved questions may lead the IAEA to request complementary access inspections or special inspections, or they may affect the periodic inspection plan for future inspections of that state or facility.

One approach used by analysts to investigate whether a state

Figure 5. A variety of information is analyzed for consistency in the IAEA State Evaluation Process.[12]



is conducting undeclared activities is to identify a state's needs by performing a gap analysis. The analyst may elect to compare the nuclear fuel cycle and weaponization activities required to produce a nuclear weapon against those activities present in the state in question. The analyst may then identify missing needs and target these areas for deeper investigation. Critical technologies may include the following:

- Fissile material production and handling
- Uranium enrichment and facilities with isotope separation capabilities
- Weapons-usable plutonium production reactors
- Plutonium separation and purification (reprocessing) and metallurgy technologies
- Criticality and health physics
- Weaponization
- Electronic fire-sets, fusing/detonation, high-explosives testing, modeling, delivery vehicle development, and so on

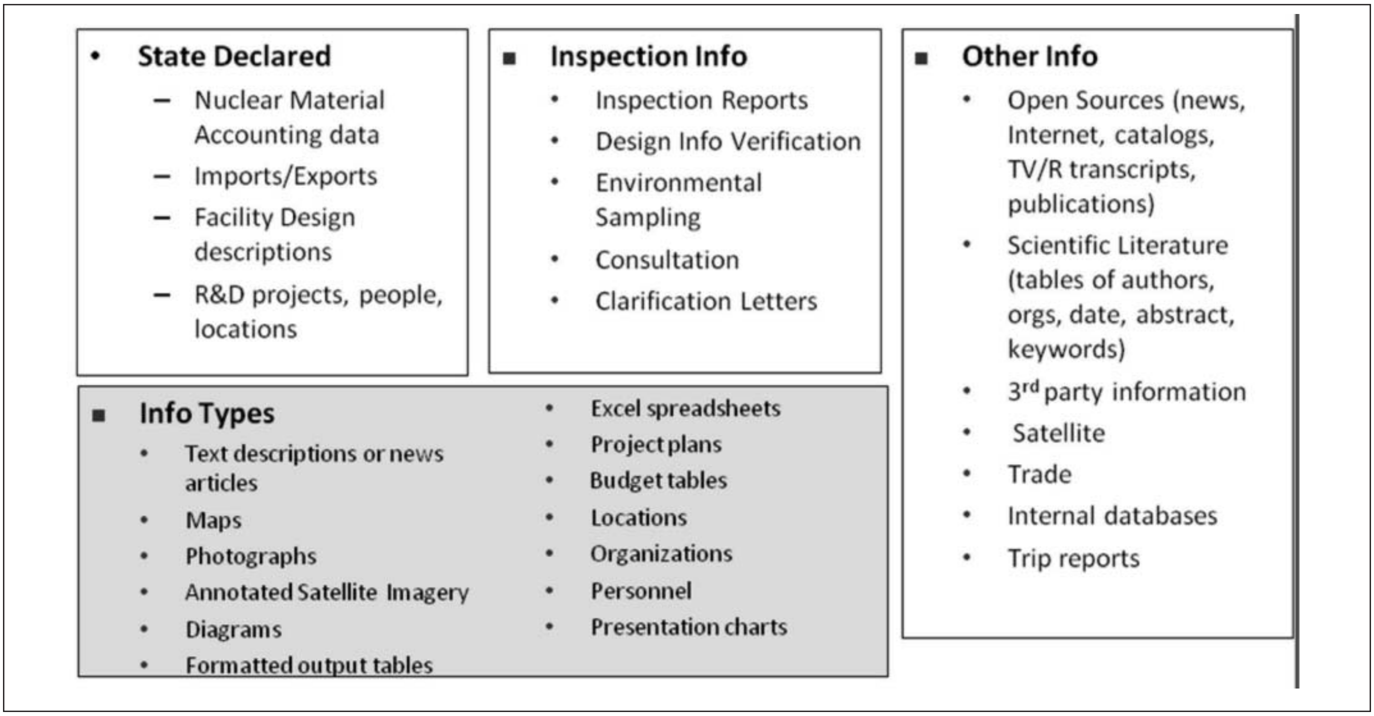
Technical R&D information that might be most useful would be experimental studies in fields related to fissile material production, weaponization, and relevant facilities and activities that are not publicly declared or acknowledged by the State. The analyst is looking primarily for trends and patterns in R&D, not just topical research. This implies the need to build databases of topics, authors, affiliated individuals, and institutions and to look for relationships and patterns over time.

The five greatest challenges to using open-source information to answer a specific nonproliferation question include the following:

1. *Scarcity of information.* Sometimes there is little information available on a particular individual, organization, or activity. Example: Tightly controlled information on possible North Korean uranium enrichment activities.
2. *Information overload.* In other cases, the vast amount of information available on a particular topic requires advanced analysis techniques and careful selection to concentrate on the highest-priority, most-reliable information. Example: The nuclear fuel cycle infrastructure in Japan.
3. *Validation.* Open-source researchers must remain aware that inaccurate and deliberately false or misleading information is common. Many sources have an established political agenda and look for facts and conclusions that support their point of view.
4. *Language barriers.* The most-detailed information is often found in the native language of a country, which might not be widely spoken by analysts. Such a situation also complicates forming effective information search strategies. In addition, summaries based on translations are seldom as reliable as original-language articles.
5. *Information analysis.* Collecting, organizing, determining associations, tracking, and drawing key results from a wide variety of information types can be daunting tasks. Example: Given the information on the Iran nuclear program, is it most likely purely civilian, or is it partially a military program? The analysis also includes a determination of the reliability of the available information.

Open sources are increasingly numerous and continually changing. Most information is textual, with some graphical content (such as images that can include both satellite and ground photographs, organization charts, process flow sheets, site dia-

Figure 6. Nonproliferation evaluations must integrate a wide variety of information types



grams, infrastructure schematics, or building blueprints). Sources exist in multiple formats and languages, with varying levels of detail and accuracy. Open sources alone are unlikely, in isolation, to produce definitive proof of undeclared proliferation-related activity, although this occasionally happens, as in the case of Iran.[11] Open-source information tends to be indirect and circumstantial, so a wide range of sources must be scanned for multiple independent types of evidence. The key results from careful analysis of open sources are usually identification of interests; names and locations of people, projects, and organizations; patterns; and connections.

Since 2000, when satellite imagery with spatial resolution on the order of one meter became commercially available, the IAEA has begun using satellite imagery as an important, independent information source to complement information from states, open sources, and third parties, as well as to support planning of verification activities. Information from satellite imagery is used by the IAEA to support the following activities:

- Evaluation and investigation of alleged or newly revealed undeclared nuclear sites (such as the Iranian uranium enrichment facility at Natanz that was alleged in open sources in 2002)
- Monitoring of critical nuclear sites to detect major changes or additions to facilities
- Preparation for complementary access and other inspection activities
- Verification of state-declared information (e.g., facility design information or Additional Protocol Article 2.a(ii) site declarations) to establish whether relevant facilities are undeclared (such as occurred at Tuwaitha in Iraq prior to 1991 and in DPRK).

Recent Advances in Information Collection, Processing, and Analysis

There have been a number of advances related to open-source information collection, processing, and analysis that help the typical analyst manage multiple challenges related to the constantly expanding, changing nature of information.

Current Advances in Information Collection

- Expanding range of online sources
  - Science and technology (S&T) literature, conference agendas and proceedings, regional business databases, Internet Web sites (company, organization, personal sites), commercial and nonprofit analysis sites/publications, internal documents
- "Federated" or simultaneous search technologies (fast)
  - Surface Web (html, pdf), deep Web (SDB, html, pdf, WP) commercial S&T databases (SDB), in-house databases, news feeds (text), graphics (photos, schematics, maps, geographical) databases, etc.
  - Automatic feed of relevant information to local databases or analytical systems

- Anonymous Internet search capabilities
- Name aliases and phonetic searches
- Advanced machine translation
  - Automatic query translation, search generation, and results translation
  - Summarizing websites and documents

Current Advances in Information Processing

- Duplicate removal (how exactly must they match?)
- Automatic entity extraction from text
- Advances in machine translation
  - Summarizing websites and documents
- Improved relevance ranking of search results

Current Advances in Information Analysis

- Integrated analysis of different types of information (unstructured text, SDB, graphics, geographical information, etc.)
- Automatic extraction of relationships, links, and associations
- Geospatial information system to spatially organize data
- Simplified user interfaces
  - Minimal training *and maintenance* requirements
  - Visual and graphical link/association analysis
- Improved collaboration analysis tools (especially visual)
- Improved, secure distribution systems for analytical results
- Cost reductions owing to lower-cost tools and improved analysis efficiency

Future Needs for Open-Source Analysis

Although the recent advances in open-source information management improve an analyst's ability to handle a growing volume of data, the accuracy, comprehensiveness, maintainability, cost, speed, and/or ease of use for the tools just described may be insufficient, prohibitive, or overrated, leaving the analyst with the same or new needs. Additional improvements are needed in the following areas.

Ease of Use

Important issues for many analysts are the ease of both installation and configuration of a software tool and minimal training time for effective use of the tool. Some analysts do not have the full-time support of an information-processing department or programmers to convert large data sets into formats convenient for further analysis. In addition, many excellent software tools have been introduced to analysts but not used often or effectively because the analysts simply do not have the weeks of time needed to be trained and gain experience with these newer tools.

Computerized Language Translation and Search

Automatic language translation has been an elusive goal for many years. However, the capabilities of such systems are gradually improving as new algorithms are developed and as computers become more powerful. What is really needed for nonproliferation analysis is a tool that can accept an English-language query, translate the query into effective target keywords in a foreign language, conduct a search for relevant sources in that language, and then translate the results back into English for presentation to the analyst.

Such tools are being developed, but machine translations are still limited in accuracy and comprehensiveness. Unfortunately, such tools are most needed for languages that are most difficult to translate into English. Many Western publications, especially S&T literature, are already available in English; however, many publications in Arabic, Farsi, Korean, Chinese, and Japanese are not currently translated. Better tools for the English-speaking analysts to use for accessing these data are needed. It should be kept in mind, however, that the optimum means for assessing foreign-language S&T literature for proliferation analysis is to have analysts that are both language trained and knowledgeable in the technical aspects of nuclear proliferation.

Entity Extraction

Much nonproliferation open-source data is in unstructured text or graphical formats. Extracting specific entities from these data and transforming the data into a universal storage format (perhaps XML) or a relational data format that can be used for further processing is a rapidly evolving field. Again, some of the issues involve recognition of a complete set of entities, language differences, and the complexity of software installation and use. In addition, some of these systems are currently prohibitively expensive for many small analytical groups.

Better tools are needed to automate the extraction of "relational events" from free-form text—not only who or what but why, when, where, and how. A solution would enable analytical processing by automating the transformation of written language into structured, relational data. The result would allow dramatically faster and more-comprehensive detection of trends, anomalies, patterns, and linkages. Once extracted in this structured form, the information can be pushed downstream to feed virtually any system that processes relational tables. Such tabular data can be stored in a shared data warehouse repository for data mining or link analysis purposes. For example, it can be input directly to a link analysis tool such as *EAS, Visual Links, Analyst Notebook,* or *SmartDiscovery* for further analysis, or it could be sent by way of an automated email alert to an analyst. Currently, however, these tools are rather complex and expensive enterprise-based solutions. A wider variety of more-user-friendly entries in the field of entity extraction and categorization of unstructured text data is needed.

Eliminating Duplicates

Many different news media might pick up the same story from multiple sources. Sometimes these accounts contain useful complementary information; however, they often just repeat the same information. An S&T search using several different bibliographic databases may contain a large number of duplicate references, with each source providing only a small (but perhaps important) number of unique entries. The data collector or analyst needs an automated method to eliminate such duplicates. This capability is needed for both structured data (S&T references, entities extracted, tabular data) and unstructured data (text reports).

Expanded Data Sources

Although not technically a software tool, new databases of open-source information related to international nuclear activities could greatly assist the job of tracking proliferation. Databases that are needed include detailed information on global imports and exports (particularly export applications that are denied by virtue of nuclear or dual-use regulations), data on criminal records, and expanded data on businesses in non-Western countries.

Summary

Advancements in information collection and analysis will continue to improve the use of open-source information for nuclear nonproliferation detection. Key technologies will include the following abilities:

- Anonymously ferreting out obscure information from numerous sources that are in different formats and a variety of languages, using simple interfaces (with a single query)
- Combining that information and extracting relevant data
- Rapidly analyzing the relevance of vast amounts of information and presenting an integrated, intuitive summary to the analyst

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Major portions of this paper are adapted from the following references:

1. Anzelon, G. 2008. IAEA Investigation of Undeclared Activities: Lessons and Prospects, *Proceedings of the INMM/ESARDA Workshop on Meeting Safeguards Challenges in an Expanding Nuclear World*.
2. Mathews, C., R. Hooper, G. Anzelon, J. Essner, J. Tape, and R. Wallace. 2008. *The International Atomic Energy Agency State Evaluation Process: The Role of Information and Analysis In Reaching Safeguards Conclusions,* Unpublished report for DOE/NNSA.
3. Wallace, R., and A. Lundy. 2008. In *Nuclear Safeguards, Security and Nonproliferation,* James E. Doyle, Ed., Butterworth-Heinemann.
4. IAEA Department of Safeguards. 2007. *Staying Ahead of the Game,* available on the IAEA Web site (http://www.iaea.org/Publications/Booklets/Safeguards3/safeguards0707.pdf).

A major reference for the use of open-source (commercial) satellite imagery in nonproliferation analysis is the following:

5. Pabian, F. 2008. In *Nuclear Safeguards, Security and Nonproliferation,* James E. Doyle, Ed., Butterworth-Heinemann.

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Notes

1. INFCIRC/153 (Corrected), June 1972.
2. 1988. Taipei Halts Work on Secret Plant to Make Nuclear Bomb Ingredient, *The New York Times,* March 23, 1988.
3. The appearance of this allegation preceded by a few years the IAEA's 1991 decision requesting parties with CSAs to modify their Subsequent Arrangements to require early notification of a decision to construct nuclear facilities.
4. See, for example, Institute for Science and International Security, "Export Control Case Studies: SMB," www.isis-online.org.
5. See UN Security Council Report, S/22788, 15 July 1991, and also Dimitri Perricos, "Uncovering the Secret Program—Initial Inspections," a talk given at the ISIS 2001 conference on Iraq, available at http://www.isis-online.org/publications/iraq/perricos.html.
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9. 2004. *Implementation of the NPT Safeguards Agreement in the Republic of Korea,* GOV/204/84, 11 November 2004.
10. 2005. *Implementation of the NPT Safeguards Agreement in the Arab Republic of Egypt,* GOV/2005/9, 14 February 2005.
11. Violations of Iran's safeguards agreement (related to uranium centrifuge enrichment and heavy water production) were alleged in public announcements of an Iranian dissident group, verified by commercially available overhead imagery, proven by subsequent IAEA inspections, and finally admitted by Iran. (See IAEA DG report to BOG, GOV/2004/83, November 15, 2004, and David Albright, I ISIS report, February 20, 2003.)
12. IAEA Safeguards. 2007. *Staying Ahead of the Game.*

Safeguards Information from Satellite Imagery

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Abstract

Today, images acquired from civil or commercial remote sensing satellites are a fundamental open source for the increasingly information-driven International Atomic Energy Agency (IAEA) safeguards. The main applications of satellite imagery are to verify the correctness and completeness of the member states' declarations, and to provide preparatory information for inspections, complimentary access and other technical visits. The aim of this article is to show the possibilities and limits of gathering safeguards information from satellite imagery. The article starts with an overview on the state-of-the-art and future civil and commercial satellite sensors technologies with regard to NPT verification. Based on this, the variety of different safeguards information that can be extracted from satellite imagery will be presented.

Introduction

Since the advent of the first very high-resolution satellite sensor IKONOS-2 in 1999, the use of satellite imagery in the nuclear safeguards system has gained tremendously in importance. Today, images acquired from civil or commercial remote sensing satellites are a fundamental open source for the increasingly information-driven International Atomic Energy Agency (IAEA) safeguards.[1,2] The main applications of satellite imagery are to verify the correctness and completeness of the member states' declarations, and to provide preparatory information for inspections, complimentary access, and other technical visits. If the area of interest is not accessible, remote-sensing sensors provide one of the few opportunities of gathering information.

The use of satellite imagery for nuclear safeguards applications has been often limited to optical data from the visible part of the electromagnetic spectrum so far, for at least two reasons: First, from a technical point of view, optical data from the visible (and near infrared) spectrum still offers the best spatial (submeter) resolution. Second, from the image analysts' point of view, the interpretation of visible data is much easier than analyzing thermal infrared, hyperspectral, or radar images, where extensive (pre-) processing is required.

Nonetheless, satellite data of all available sensor types contains a considerable amount of safeguards-relevant information:

- Very high-resolution *optical* satellite imagery provides the most detailed spatial information on nuclear plants. Furthermore, the stereo capabilities of the sensors allow the extraction of high-resolution Digital Surface Models (DSMs) for 3D visualization of the sites and the surroundings.
- *Thermal infrared* images, measuring thermal radiation from the earth surface, display heat emissions and thermal anomalies. Therefore, thermal remote sensing data can indicate the operational status of nuclear facilities and help to identify undeclared activities.
- *Hyperspectral* sensors record the reflected radiation in several hundreds of very narrow contiguous or overlapping wavelength bands from visible to mid infrared. Hyperspectral data allows a quantitative estimation of geophysical, geochemical and biochemical characteristics of the earth's surface and is therefore useful for assessing, for example, surface cover changes due to drilling, mining, and milling activities.
- *Synthetic Aperture Radar (SAR)* image data provide an all-weather, day and night monitoring capability. Methods such as coherent change detection, interferometry and polarimetry help to extract information on the surface cover (i.e., infrastructure of the facility) as well as on surface and terrain heights, surface movements and deformations due to drilling, mining or camouflage.

However, the absence (or existence) of nuclear activities can never be confirmed completely based on satellite imagery. In fact, image data always needs to be analyzed in conjunction with collateral data, such as inspection results and/or non-image information from other (open) sources. In-depth technical knowledge about the nuclear fuel cycle and its processes is another fundamental requirement for analyzing satellite imagery effectively.

The aim of this article is to show the possibilities and limits of gathering safeguards information from satellite imagery. We start with an overview on the state-of-the-art and future civil and commercial satellite sensors technologies with regard to Nonproliferation Treaty (NPT) verification. Based on this, the variety of different safeguards information that can be extracted from satellite imagery will be presented.

Satellite Imagery: Trends in Sensor Technologies as to Safeguards Information

The first civil satellite was launched by the U.S. National Aeronautics and Space Administration (NASA) in 1972. Earth Resources Technology Satellite (ERTS), renamed as Landsat-1,

Table 1. Very high-resolution optical imaging sensors (≤ 1 m spatial resolution) currently or planned to be in orbit by 2011, ordered by best spatial resolution and launch date

Sensor	Operator (Country)	Launch	Spatial resolution [m]	Revisit time [days]
GeoEye-1	GeoEye (USA)	09/2008	0.41 (PAN), 1.64 (VNIR)	2.1 - 8.3
WorldView-1	DigitalGlobe (USA)	09/2007	0.45 (PAN)	1.7 - 5.9
WorldView-2	*DigitalGlobe (USA)*	*2009 ?*	*0.45 (PAN), 1.84 (VNIR)*	*1.1 - 3.7*
QuickBird-2	DigitalGlobe (USA)	10/2001	0.62 (PAN), 2.44 (VNIR)	3 – 7
EROS-B	ImageSat (Israel)	04/2006	0.7 (PAN)	2.5 – 10.5
EROS-C	*ImageSat (Israel)*	*2009 ?*	*0.7 (PAN), 2.5 (VNIR)*	*min. 3*
Pleiades-1	*CNES (France)*	*2010 ?*	*0.7 (PAN), 2.8 (VNIR)*	*min. 3*
Pleiades-2	*CNES (France)*	*2011 ?*	*0.7 (PAN), 2.8 (VNIR)*	*min. 3*
IRS Cartosat-2	ISR (Indien)	01/2007	0.8 (PAN)	min. 4
IRS Cartosat-2A	ISR (Indien)	04/2008	0.8 (PAN)	min. 4
IKONOS-2	GeoEye (USA)	09/1999	1 (PAN), 4 (VNIR)	appr. 3
Resurs DK-1	Russia	06/2006	1 (PAN), 3 (VNIR)	?
Kompsat-2	Kari/EADS (South Korea)	07/2006	1 (PAN), 4 (VNIR)	appr. 3

PAN: panchromatic; VNIR: visible and near infrared spectrum
standard font type: launched satellite; italic: to be launched;
grey background: commercial satellite data; white background: non-commercial national satellite, data possibly available for research purposes
(Sources: Companies' Web sites, http://directory.eoportal.org/, http://www.space-risks.com)

provided image data in three spectral bands (green, red, near infrared) with a spatial resolution of 80 m. Thirty-seven years later, considerable advances have been made in sensor capabilities. Today, the following spectral and spatial options are commercially available:

- Very high-resolution optical data with a resolution up to 0.41 m, up to four spectral bands (blue, green, red, near infrared) and stereo capabilities;
- 30 m short wave/mid infrared data;
- thermal infrared data with a resolution of 60 m and 90 m;
- hyperspectral data at 30 m resolution;
- high-resolution Synthetic Aperture Radar (SAR) data up to 1 m spatial resolution, offering quadrature polarisation (quad-pol).

Optical Imaging Sensors

Table 1 gives an overview on current and future very high-resolution optical imaging sensors. Only sensors with a spatial resolution of 1 m or better are listed and ordered by their best spatial resolution and launch date. Seven systems are privately owned by two U.S. companies (GeoEye, DigitalGlobe) and an Israeli enterprise (ImageSat), another six systems are under operation or development by the national space agencies of France, India, Russia, and South Korea. Most of the sensors include multispectral bands from the visible and near infrared spectrum, all listed systems offer along- and cross-track stereo capabilities and the scene size varies between 10 by 10 km^2 and 28 by 28 km^2.

SAR Imaging Sensors

SAR sensors with a spatial resolution from 3 m are listed in Table 2. Both satellites with a commercial payload, TerraSAR-X and Radarsat-2, were realized as Public Private Partnership (PPP) between the national space agency and industry. Depending on the acquisition mode, different swath widths and polarization modes are available. Polarization refers to the orientation of the radar beam relative to the earth's surface, either horizontal (H) or vertical (V). Radar systems capable of sending and receiving radar waves both horizontally and vertically could in principle produce co-polarized signals (HH, i.e., transmit H - receive H, and VV) and cross-polarized signals (HV and VH).

Table 2. High-resolution SAR imaging sensors (≤ 3 m spatial resolution) currently or planned to be in orbit by 2010, ordered by best spatial resolution and launch date

Sensor	Company (Country)	Launch	Spatial resolution [m]	Frequency [GHz]	Revisit time [days]
TerraSAR-X	DLR/Astrium *(Germany)*	06/2007	1	9.65 (X)	11
Tandem-X	*DLR/Astrium (Germany)*	*2009 ?*	*1*	*9.65 (X)*	11
COSMO-Skymed 1-4	ASI (Italy)	1: 06/2007 2: 12/2007 3: 10/2008	1	9.6 (X)	< 1 (4 Sat)
RADARSAT-2	CSA (Canada)	12/2007	3	5.405 (C)	?

PAN: panchromatic; VNIR: visible and near infrared spectrum
standard font type: launched satellite; italic: to be launched
grey background: commercial satellite data; white background: non-commercial national satellite, data possibly available for research purposes
(Source: Companies' Web sites, http://directory.eoportal.org/, http://www.space-risks.com)

In the case of fully polarimetric (so-called quad-pol) datasets, four different polarization channels (HH, HV, VV and VH) are acquired per image. The information provided by quad-pol data enhances the possibilities to derive properties of the earth's surface.

For the highest possible spatial resolution, TerraSAR-X offers single polarization (HH or VV) at 1.1 m and dual polarization (HH and VV) at 2.2 m for a scene size of 10km (cross) by 5 km (along). Radarsat-2 generates selective single polarization (HH or VV or HV or VH) at 3 m and a scene size of 20 by 20 km^2. Fully polarimetric datasets are available from Radarsat-2 at 8 m spatial resolution and a scene size of 25 by 25 km^2, while the quad-pol capabilities on TerraSAR are currently being investigated in an experimental mode. As soon as this mode is operationally qualified and the product characteristics have been assessed, also full polarimetric products may become available.[3]

Thermal Infrared Imaging Sensors

Spaceborne thermal infrared sensors with a commercial payload are today limited to three satellites: Landsat-5 and -7, both part of the Landsat's Global Survey Mission of U.S. Geological Survey (USGS) and the NASA, and Terra, the flagship satellite of NASA's Earth Observing Systems (EOS). The imaging instruments Thematic Mapper (TM) carried onboard Landsat-5 and Enhanced Thematic Mapper Plus (ETM+) on Landsat-7 acquire data in one spectral band between 10.40 and 12.50 µm in 120 m (TM) and 60 m (ETM+) spatial resolution, the ASTER instrument onboard Terra offers 90 m resolution in five spectral bands between 8.125 and 11.65 µm. Launched in 1984 (Landsat-5) and 1999 (Landsat-7, Terra), all three satellites have exceeded by far their design lifetime and already started to fall off in quality. By 2010 (Landsat) and 2015 (Terra) it is expected that the satellites exhaust their fuel supply; however, the satellites could fail at any time.

For applying thermal infrared imagery within nuclear safeguards, technical enhancements as to spatial resolution would be necessary, but not even a continuation of the given missions is assured. The Landsat Data Continuity Mission (LDCM) considers a thermal imaging instrument only as an option and without additional funding, NASA will probably place the next Landsat satellite by 2011 without a thermal infrared sensor. For the ASTER instrument, a cooperative effort between NASA, Japan's Ministry of Economy, Trade, and Industry (METI) and Japan's Earth Remote Sensing Data Analysis Center (ERSDAC), no further developments are foreseeable for the time being.

Hyperspectral Imaging Sensors

The only satellite-based hyperspectral instrument today, Hyperion, is flying onboard the Earth Orbiter-1 (EO-1) spacecraft, launched in 2000 under NASA's New Millennium Program (NMP). Hyperion provides 220 spectral bands from 0.4 to 2.5 µm at a scene size of 7.5 by 100 km^2. Like the thermal infrared sensors, the spatial resolution of 30 m is a limiting factor for the application of hyperspectral data in a number of nuclear monitoring applications. Moreover, the Hyperion image data comes along with huge noise effects, i.e., the signal-to-noise ratio hinders the analysis. The latter, however, is expected to be improved by the Canadian Hyperspectral Environment and Resource Observer (HERO) mission[4] and the German Environmental Monitoring and Analysis Program (EnMap).[5]

Availability of Satellite Imagery

Commercial satellite image data are generally available, unless national security is at risk. The U.S. government for instance has included export control restrictions and the right to shut down satellites (so-called shutter control) in licenses for commercial providers. So far, true shutter control has never been implemented, though resolution control is being applied to ban sales of imagery below a certain spatial resolution.[6] U.S. licenses prohibit the sale of imagery below 0.5 m resolution to commercial costumers—with an exception for coverage of Israel, where the resolution is restricted to 2 m per pixel. Furthermore, priority costumers may exclude others from buying images of certain areas. During Operation Enduring Freedom for example, the U.S. Department of Defense exclusively bought all imagery acquired over Afghanistan. In addition, the Bush administration was able to convince the French Defense Ministry to prevent Spot Image from selling Spot images over Afghanistan.[6]

Some of the systems listed in Tables 1 and 2 and earlier in this paper, such as the national satellites Pleiades (France), Cosmo-Skymed (Italy), Cartosat-2A (India), but also the European satellites Sentinels 1-5 as part of the EU/ESA-funded initiative "Global Monitoring for Environment and Security" (GMES) are dual-use systems. How the data will be shared between military and civilian users, has not been revealed yet. However, as more and more countries are developing (very) high-resolution commercial satellites, the current restrictions may become less important in the future.

From Data to Information: Extraction of Safeguards Information from Satellite Imagery

Image information extraction covers the whole range of obtaining spatial, spectral (reflective, emissive), polarization, temporal, and/or semantic properties of image pixels or image objects by visual and/or computer-based analysis.

Before analyzing, satellite imagery requires some pre-processing steps in order to correct the radiance differences caused by variations in solar illumination, atmospheric conditions, sensor performance and geometric distortion respectively. Image enhancement aims to increase the appearance of an image for visual interpretation or subsequent digital analysis. The state-of-the-art remote sensing software systems, such as ENVI, PCI Geomatica and ERDAS IMAGINE, offer various pre-processing tools for:

- atmospheric correction of multispectral and hyperspectral image data by atmospheric modeling or radiometric normalization;
- geometric correction of optical and radar satellite image data through geocoding, georeferencing, image registration, orthorectification;
- noise reduction of radar image data by (speckle) filtering;

and a number of image enhancement procedures, among others for

- pan-sharpening and image fusion, especially for optical imagery;
- dimension reduction of multispectral and hyperspectral image data through principal component analysis or minimum noise fraction transformation;
- emissivity and kinetic surface temperature estimation in case of thermal infrared data.

Besides, more promising computer-based tools for both preprocessing and image enhancement exist in literature. Some of them have been implemented as ENVI extensions and become available throughout.[7]

For monitoring declared nuclear facilities or detecting clandestine activities using satellite imagery, specific object features related to the nuclear fuel cycle and its processes as well as geographical and cultural characteristics need to be surveyed. An imagery analyst has to identify objects regarding size, shape, height, color, surroundings, functionalities, and temporal changes, and determine their significance.[8] But which type of safeguards information can be extracted from satellite imagery?

Site Description

Very high-resolution optical satellite imagery as provided by the sensors listed in Table 1 involves the most detailed spatial information on nuclear sites. Figure 1 shows an extract of a pan-sharpened QuickBird scene acquired over the NFRPC Esfahan in July 2003 as an example. Since many details can be identified, this type of data provides a good basis for analyzing the facilities' installations and verifying design information and Additional Protocol declarations.

Furthermore, the stereo capabilities of the sensors allow the extraction of high-resolution Digital Surface Models (DSMs) for 3D visualization of the sites and the surroundings.

Due to the large stereo angles of standard QuickBird stereo pairs, fully automatic methods for extracting building shapes do not show satisfactory results so far. According to Reference 9, a semi-automatic procedure that uses manually measured tie lines at the building edges in addition to the automatic generated tie points shows improved results (Figure 2).

DSMs can also be derived from high-resolution SAR imagery by applying either radargrammetric or interferometric techniques. Some current research studies investigate whether SAR image analysis can meet the expectations with regard to safeguards applications.

2D and 3D Change information

Image acquired over the same area of interest at different acquisition times can be compared visually or by computer-driven processing techniques[9,10] in order to assess the safeguards relevant changes, such as construction of buildings or streets, surface movements due to underground activities and others.

As an example for automated change detection, Figure 3 shows the visualization of changes at one site based on the so-called Multivariate Alteration Detection (MAD). Applying the

Figure 1. Extract of a pan-sharpened QuickBird scene acquired over the NFRPC Esfahan in July 2003

Figure 2. Extraction of building heights from QuickBird stereo pairs. Left: semi-automated extraction using a pseudo stereo pair acquired in June 2004 and July 2004); right: automated extraction acquired on November 2005[9]

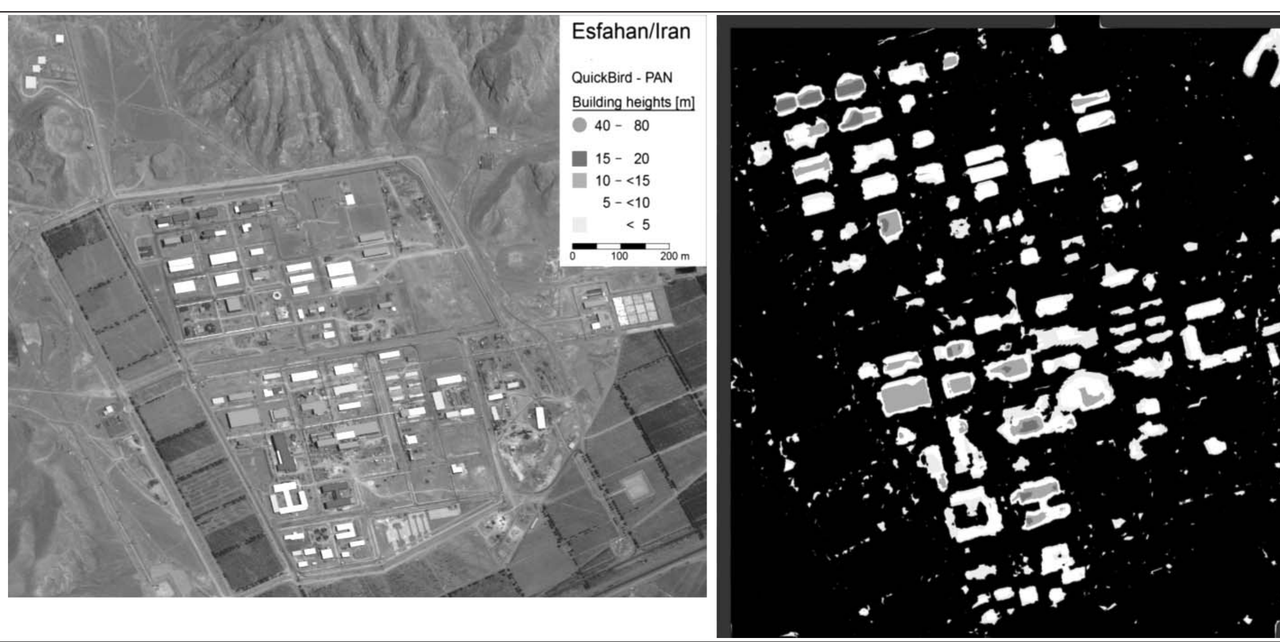


Figure 3. Change visualization tool. Left: Overview; right: zoom. The top images show the situation at the site of interest at two different acquisitions times. The right hand images in the bottom line present the change components, the left hand images the change intensity.

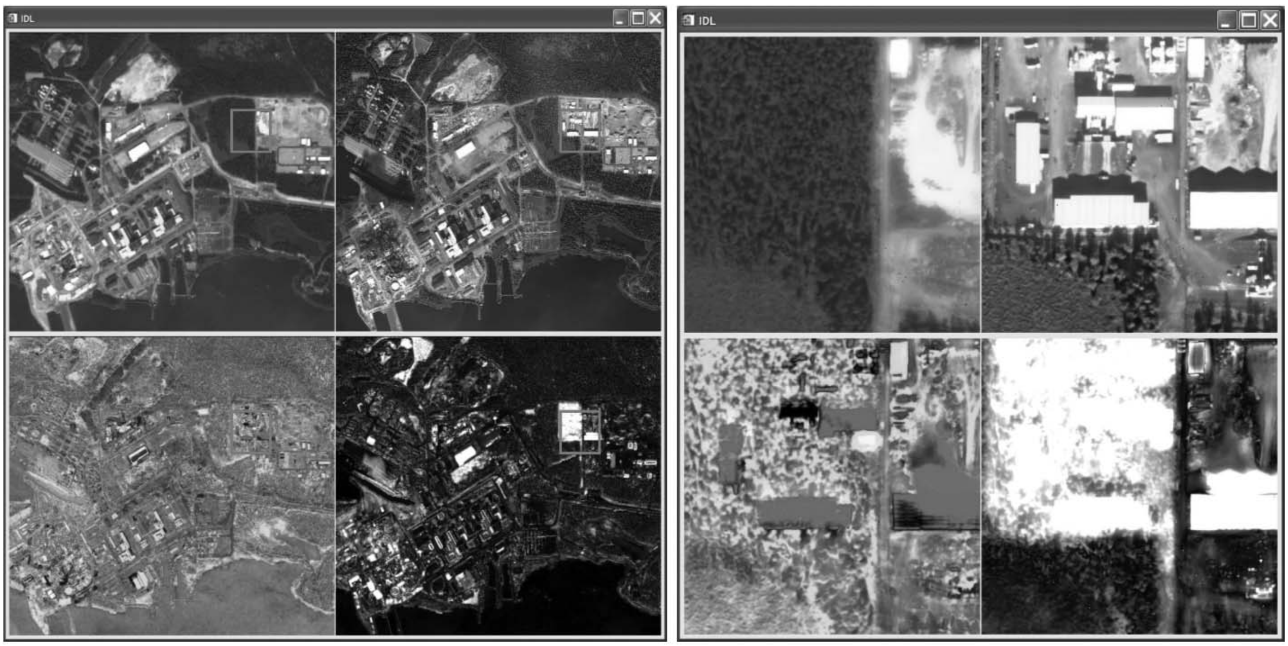


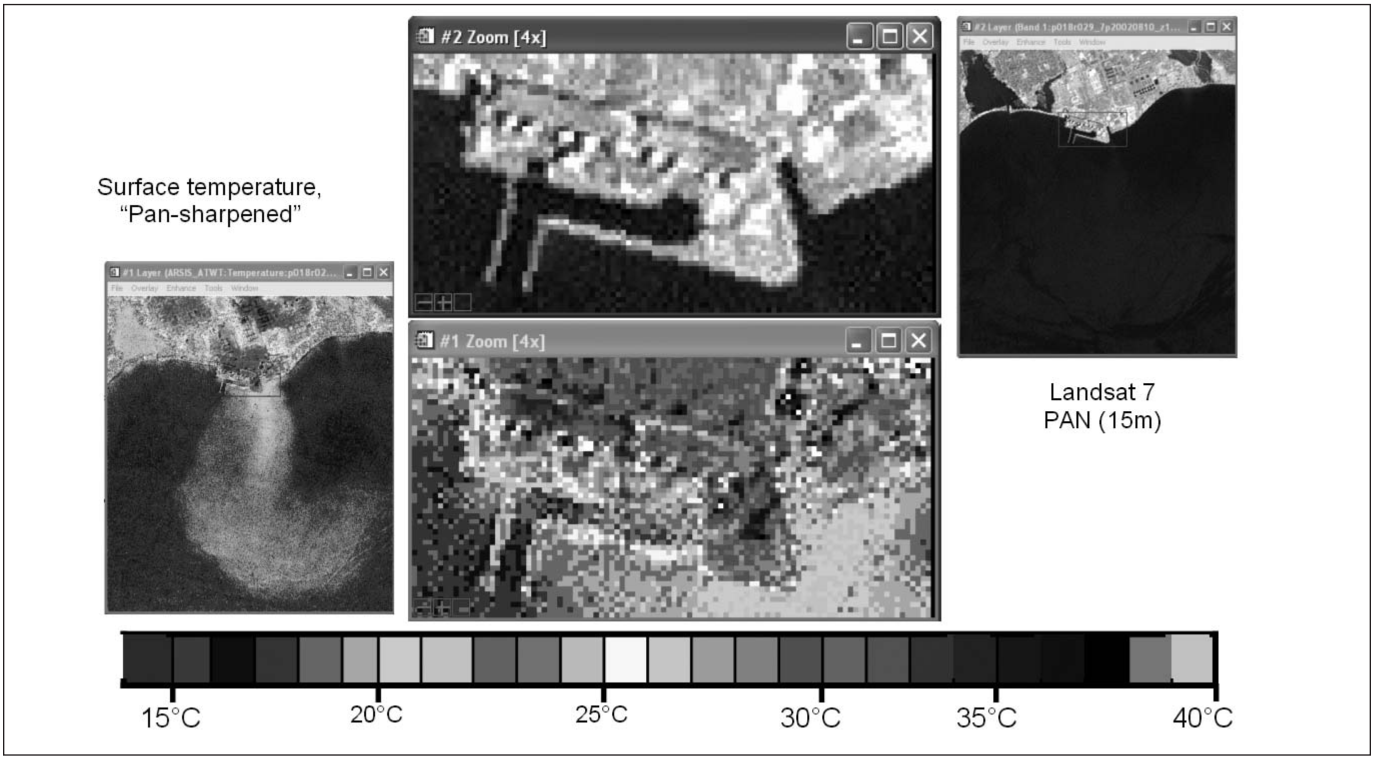
Figure 4: Change detection based on the object features. Left: QuickBird data acquired at time 1; right: QuickBird data acquired at time 2 plus the changes detected through MADs 12, 15 and 16.

MAD on a bi-temporal dataset with n spectral bands enhances the change information in the two images by calculating *n* so-called MAD components and also estimates the change intensity.

The MAD can also be applied on image objects and its object features, such as color, texture, etc. Figure 4 illustrates the changes detected through three of the calculated MAD components.

Information on 3D changes can be estimated based on the comparison of DSMs generated for different acquisition times. Studies on 3D change detection using optical stereo pairs were performed (see references 11 and 12). Moreover, 2D or 3D change information as to building construction or surface movements can also be extracted from SAR images by using interferometric or coherent change detection techniques. Some studies were carried out using medium resolution SAR13 and are recently in progress using high-resolution SAR.

Figure 5. Surface temperatures given by LANDSAT 7 (August 10, 2002; ~ 11:00 a.m. local time; 27°C air temperature; clear conditions) fused with LANDSAT Pan (15m spatial resolution)[14]



Operational Status of Facilities

Thermal infrared remote sensing data provides safeguards-relevant information, even though the spatial resolution is relatively low. After converting the thermal infrared data to emissivity and temperatures, image fusion (here: discrete wavelet transform) with bands of higher spatial resolution facilitates the interpretation of the temperatures (Figure 5). Anomaly detection tools are useful for extracting "hot spots" in a specific region or the whole scene.

Identification of the Surface Materials

Using well-calibrated hyperspectral imagery, surface materials can be characterised, identified and potentially tracked from source to destination.[15] By fusing the results of lower resolution hyperspectral analysis results with high-spatial resolution imagery, objects, and information on materials can be identified simultaneously.

Image Information Management

Working with huge archives of satellite imagery requires a specific image data management, rather than analyzing single scenes stored in a specific file directory. Software systems are needed that enable the image analyst not only to access the data, but also the safeguards-related information in the imagery database.

In traditional geodatabase approaches, the areas of interests are retrieved by querying on the metadata, such as coordinates, time of acquisition, sensor type, etc., and processed subsequently. However, information provided by the metadata may often be less relevant in terms of nuclear safeguards. Particularly for the detection of undeclared activities, the image analyst may neither know exactly the area of interest nor the time of the event. Recent developments as to image information mining and content-based image retrieval techniques are eminently suitable for designing an user-friendly and intelligent image information management system.

Image information mining is the process to automatically discover useful (and maybe previously unknown) information in large image databases. Content-based image retrieval enables the user to access the relevant image data by querying the image content, such as colors, shapes, textures, context, or any other information that can be derived from the image itself. First studies on applying content-based image retrieval procedures for nuclear monitoring have shown promising results[16,17] and will be further investigated.

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Safeguards Technology Meets New Challenges

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Abstract

The safeguards technology development community must continue to supply solutions to new safeguards requirements. In some cases, these solutions are evolutionary changes to existing equipment required to address changes in the underlying technologies, in other cases they are required to address changes in the missions of the safeguards agencies, and finally they must also address the increasing capabilities of potential adversaries. In addition, revolutionary changes and completely new approaches are required to address new safeguards requirements, such as detecting undeclared activities.

This paper discusses a wide range of technology development activities, but it certainly does not cover the entire list of the activities currently ongoing. The authors apologize to those whose efforts were not included in the paper. The objective was to give the reader some insight into the nature of the activities and the motivations for them.

Introduction

The job for the agencies tasked with international safeguards is continuing to expand much faster than their budgets. More reactors are being built and more bulk processing facilities are coming on line. These facilities include uranium enrichment plants, spent fuel reprocessing plants, and fuel fabrication facilities. These new facilities are larger and more automated, making inspector access much more difficult. Many of these facilities have huge throughputs of heavy metal, which means that the normal measurement errors associated with safeguards measurements can represent many significant quantities of nuclear material. Monitoring activities at these facilities result in huge data streams that must be processed and analyzed. All of the data processing must be done without a proportional increase in funding or staff.

The following are some of the challenges currently being addressed in the safeguards technology community:

- Equipment must continually evolve to take advantage of new technologies and to replace equipment that is no longer economical to produce or to maintain. Section 2 of this paper discusses some of these activities.
- The efficiency of inspection activities must improve to allow the inspectors to monitor more facilities and activities. In order to accomplish this, more use of unattended and remote monitoring technologies should be used to reduce the need for inspector travel. The time the inspector spends at the facility must be as productive as possible. For example, the need for physical inspection of equipment and tamper indicating devices and enclosures can be minimized by using more active tamper indication technologies and by cryptographically authenticating the data at the source. There is some discussion of this in Section 2.
- Reducing the number of destructive analysis samples that must be collected and processed greatly reduces inspector effort while also reducing the time required for safeguards conclusions to be reached. A method for using non-destructive assay measurements to accomplish this is discussed in Section 3.
- The accuracy of accounting measurements must be improved to allow the detection of diversion of goal quantities in a timely manner in plants with large throughput. One of the major challenges associated with this is in the accurate measurement of the amount of plutonium in spent fuel. A method for addressing this problem is discussed in Section 4.
- Undeclared nuclear activities must be detected. The International Atomic Energy Agency (IAEA) project to develop new and novel technologies for this purpose is discussed in Section 5.

Evolution of Safeguards Equipment

The initial safeguards measurement efforts concentrated mostly on portable gamma and neutron measurement equipment. Over the years such instrumentation has evolved from simple gross measurements to highly sophisticated spectroscopic isotope identification systems using gamma detectors[1,2,3,4] and from gross neutron measurements to multiplicity systems using neutron detectors.[5] The IAEA is currently pursuing the development of the Universal NDA Platform (UNAP) to standardize the hardware and interface to as many of the detectors as possible. The UNAP includes state of the art technology for interfacing with a wide variety of detectors. It also allows the data collected to be cryptographically authenticated and encrypted.

The safeguards surveillance efforts initially started with simple time lapsed photography, which was followed by a tedious and time-consuming process of reviewing the photos. After it was acknowledged that commercial-off-the-shelf (COTS) products would not be a viable option for safeguards surveillance, the first surveillance systems developed specifically for IAEA safeguards were completed in the `80s.[6] Over the years the technology evolved to the first all-digital surveillance camera, the GEMINI.[7] The next step in the evolution of safeguards cameras was the DCM14, which was developed with funding from the German Support Program.[8,9,10] The DCM14 permitted the combination of an analog camera with a digital storage server and is still in use today. The Next Generation Surveillance System (NGSS) is currently under development[11] and will progressively replace the existing DCM14 installations beginning in 2010. All safeguards cameras are generally used in conjunction with highly automated review software tools, such as the GARS software package.[12]

The key features that make safeguards cameras different from other video monitoring equipment and that force the IAEA to pursue custom development of such instrumentation include:

- Exceptional reliability in the most severe environments, including high radiation (Single Event Upsets),[13] frequent power outages, and high temperature and humidity
- Full sustainability, maintainability, and manufacturability during a long life cycle compared to usual industry standards, while ensuring compatibility with existing and new systems
- Security of each component by providing data encryption and authentication at the source, as well as mechanisms for detecting any attempt to tamper with the system

The NGSS is needed because the components in the DCM14 are slowly becoming obsolete. In addition, the use of worldwide computer networks and the desire to have data available remotely have increased significantly since the DCM14 was designed. The NGSS system as a whole will consist of the data generator (the camera) and a data consolidator (the server). The key features are:

- Integration of the surveillance camera and the security critical data management functions into one tamper-indicating assembly
- Advanced data security (authentication and encryption)
- Short picture taking interval (PTI)
- Support for high resolution and color images
- Support for TCP/IP networking over Ethernet with co-existence with current surveillance equipment
- Modular, fully scalable system to allow simpler installation, maintenance, and spare parts logistics
- Low power consumption
- High reliability under harsh environmental conditions
- COTS and non-proprietary components where possible to facilitate an extended life cycle management
- Designed to be easily implemented as joint-use equipment (JUE)
- Built-in redundancy to reduce/eliminate single points of failures
- Storage device modular, upgradeable without modification to the rest of the system, and independent from current/future storage technology
- Power subsystem designed to operate at any voltage and frequency across the world
- Compatibility with an updated version of the GARS review software.

The NGSS is presently undergoing pre-production qualification testing and start of field testing.

A similar evolution is continuing in the area of tamper indicating devices. A new version of the Electro Optical Sealing System[14] (EOSS) has been developed and is currently being fielded to replace the VACOSS[15] fiber optic seal. The new EOSS features very advanced tamper indicating features and cryptographic data authentication.

The Secure Sensor Platform (SSP) is a battery-powered data acquisition system that is currently under development. It will interface with a variety of sensors ranging from door switches to a compact, battery-powered gamma spectrometer. The SSP features a fiber optic seal, radio frequency communications, cryptographic data authentication and data encryption. New breakthroughs in microelectronics will allow the SSP to include asymmetric data authentication for the first time in a battery operated seal. The use of asymmetric cryptography will greatly simplify the key management problem for the inspectors.

Another version of the SSP that is also currently under development is the Remotely Monitored Sealing Array (RMSA). This device does not include the sensor interfaces of the SSP in order to reduce cost and will be used only as a seal. The RMSA includes all the other features of the SSP. Operational testing should start in late 2009.

The remote monitoring capability at the IAEA is expanding rapidly to deal with the large number of new sites being monitored. They have streamlined their operations to adapt quickly and inexpensively to these new challenges. In 2006, remote monitoring saved 150 person days of inspection time, and this number continues to increase. Not only do they gather, process, and distribute state of health and other data, they have also shown that they can provide remote maintenance of equipment. For example, they can change the picture taking interval of a camera while it is operating in a remote facility with nuclear material present. Their monitoring environment was recently subjected to a vulnerability analysis to verify that they have accomplished this amazing growth without compromising security.

In the future, more of the technical review of the data will be automatically performed, providing large manpower savings. The availability of broadband Internet will become more ubiquitous with wired, fiber, and Universal Wireless Telecommunications Systems access, and the IAEA plans to use this newly available communications capability to expand remote monitoring to more facilities worldwide. This new bandwidth will also allow them to implement more bandwidth intensive applications, possibly even allowing secure video conferencing at the cabinets in the field.

NDA Techniques to Minimize the Need for Taking DA Samples

The implementation of nuclear safeguards at Pu bulk handling plants depends heavily on the destructive analysis (DA) of samples taken from the process. The provision of on-site laboratories at large plants has significantly reduced the amount of time required to obtain the results of the analysis, but there is still room for further improvement. The capacity of the laboratory is limited by the capital cost and the number of analysts that can be used. The number of samples taken can, at times, be greater than the capacity leading to delays. Some of the DA methods need reference spikes that are becoming more difficult to obtain. Also, most of the DA techniques give rise to relatively large amounts of waste that cannot be recycled and must be disposed of. For these reasons, the use of non-destructive assay (NDA) methods, in particular neutron coincidence and neutron multiplicity counting, has been investigated.[16,17,18] There are two ways in which NDA methods have potential to improve this situation. The first approach is to use NDA rather than DA techniques to measure the samples.

Neutron counting methods measure the neutron emission from the even isotopes of plutonium, along with neutrons generated by (α,n) processes. The result is usually obtained in terms of a ^{240}Pu effective value. In order to obtain the total Pu mass, it is necessary to know the isotopic composition of the plutonium. Although this can be determined by high-resolution gamma spectrometry (HRGS), the precision of this method is usually significantly worse than mass spectrometry. The following section deals with the first part of the problem, which is the precise determination of the ^{240}Pu effective mass in the item.

There are three analysis methods in common use for neutron coincidence counting: passive calibration curve,[19] "known alpha,"[19] and multiplicity analysis.[20] These three methods result in different precisions on the determination of the ^{240}Pu for the same counting time because of the way the singles, doubles and triples counting rates are used. The precision ultimately depends on the mass of the sample, the efficiency of the detector and the counting time. Measurements of small samples at Los Alamos National Laboratory (LANL) have demonstrated that precisions of 0.1 – 0.2 percent on the ^{240}Pu mass can be achieved with sufficiently long measurement times.[21,22] Further tests are underway that will include the investigation of systematic errors such as the reproducibility of sample position and Monte Carlo calculations are being carried out to determine the effect of isotopic composition, density and moisture.

A crucial step in the use of NDA methods will be the calibration. It is necessary to produce reference standards that are well characterized for systematic and random error that allow the instruments to be correctly calibrated. The International Target Values of 2000[23] give the random and systematic errors for Isotope Dilution Mass Spectrometry (IDMS) as 0.15 percent and 0.1 percent respectively, not including sampling error (the ITV are soon to be revised).

The second part of the sample measurement problem is to obtain the Pu isotopic composition, which is used to convert the ^{240}Pu effective mass into total Pu mass. The most precise Pu results from the NDA measurements will be obtained using isotopic compositions measured using mass spectrometry. However the actual procedure in any particular situation will depend on how much the isotopic composition varies in the operating process. It may be possible to use a plant- or campaign-average value. It may be adequate to make a mass spectrometry measurement once per batch, or it may even be necessary to make a mass spectrometry measurement for each sample. This latter situation is still an improvement over total DA analysis of the sample because mass spectrometry alone does not require a reference spike and does not create much radio-chemical waste. HRGS could be used on the small samples to verify the mass spectrometry values of the operator.

For small sample analysis it is conceivable that a carefully calibrated, high-efficiency neutron detector could yield ^{240}Pu effective masses with an uncertainty of 0.25 percent and Pu masses with an uncertainty of about 0.27 percent using the plutonium isotopic composition measured with mass spectrometry.

The second approach is to develop NDA instruments that can measure entire items with high accuracy. Sampling for DA plus authenticated weighing is used to give a high accuracy determination of the amount of nuclear material in a batch. An alternative is to measure all of the items with an NDA system. If the accuracy of the NDA is sufficient, then a much reduced number of samples need to be taken. This approach can be employed at many measurement points throughout bulk handing facilities. One example would be the measurement of the product of a reprocessing plant (MOX or PuO2 powder). The precision of the

NDA system can be very good because of the high statistical precision and the stability of neutron counting equipment. The accuracy of the system can be monitored by occasional samples, perhaps one in ten batches, taken for DA. Another example would be the measurement of finished MOX fuel assemblies. The calibration of such a system is very important to the accuracy and the monitoring of the detector performance, perhaps with a reference assembly, would be necessary because DA confirmation of the result is not practical.

These two approaches have the potential to yield significant advantages in terms of time of obtaining results, cost, and reduction of radioactive waste.

Determination of Plutonium Mass in Spent Fuel with Nondestructive Assay

Introduction

Although the majority of plutonium (Pu) in the world is stored in commercial spent fuel assemblies, a measurement system for quantifying the Pu mass contained in these assemblies does not exist. The nondestructive assay systems in use today (Cerenkov Viewing Device[24], Fork Detector,[25] and Safeguards MOX Python Detector[26]) measure indirect signatures from spent fuel such as gamma emission from fission fragments, or photons induced by radiation from fission fragment, or total neutron emission, which is dominantly emitted from curium. Calculation codes, known as burnup codes, can be used to infer plutonium mass from these measured signatures. In order to be used for quantifying Pu mass, these codes required input from the operator. From an international safeguards perspective, this input is undesirable given the regulatory requirement of independent verification.

Motivation

We have identified eight reasons motivating research into determining the Pu mass in spent fuel assemblies by means of nondestructive assay (NDA): (1) Provide regulators the capability to independently verify the mass of plutonium at any site with spent fuel; (2) Enable regulators and facilities to accurately quantify the Pu mass leaving one facility and arriving at another facility ("shipper/receiver difference"); (3) Provide confidence to the public that the shipment of spent fuel around the world is being undertaken in a rigorous way that assures material is not diverted during shipment; (4) Provide regulators with a tool for recovering continuity of knowledge at any site storing spent fuel; (5) Provide reactor operators with a tool enabling optimal reloading of reactor cores; (6) Provide regulators of once-through fuel cycle repositories the capability to optimally pack fuel into the repository ("burnup credit"); (7) Enable determination of the input accountability mass of an electro-chemical (pyro-chemical) processing facility; (8) Provide facility operators with a means for quantifying the Pu mass in spent fuel that is no longer considered "self-protecting." This is particularly relevant given the contemplated change by some regulatory agencies of what level of radioactivity qualifies as self-protecting.

Approach

With the goal of quantifying the Pu mass in spent fuel assemblies, researchers supported by the Nonproliferation Programs of the U.S. Department of Energy identified twelve NDA techniques that quantify various signatures from commercial spent fuel.[27] The approach for researching the capabilities of these techniques was shaped by two key factors: (1) none of the NDA techniques is capable of determining elemental Pu mass as a standalone technique; and (2) several different NDA systems will likely be needed to satisfy the unique situations of the eight motivations listed above. To expand on this point, factors such as cost, accuracy, and portability will impact what system of techniques are best for a given motivation.

The research plan started in 2009 is nominally a five-year effort. The initial two years is a Monte Carlo modeling effort with two main goals: (1) quantify the expected capability of each technique; and (2) determine how to integrate a few techniques together in order to determine elemental Pu mass. In order to cost-effectively and robustly achieve these two goals, a library of assemblies from pressurized water reactors was created that contains the following: (a) a diverse range of spent fuel (burnup, enrichment, cooling time) similar to that which exists in spent fuel pools today and in the future (sixty-four assemblies); (b) diversion scenarios that capture a range of possible rod removal options (~forty assemblies); (c) the spatial and isotopic detail needed to accurately quantify the capability of all the NDA techniques so as to enable integration (four radial zones per rod, thirty-nine unique rods). The performance of each instrument will be quantified for the full assembly library as if the measurements took place in three different media: air, water, and borated water.

The final three years of this research effort involve fabricating detectors, measuring spent fuel assemblies and, ideally, comparing the Pu mass determined by NDA of individual assemblies with the Pu mass determined with an input accountability tank and destructive analysis. Given the cost of this ideal case, other approaches to researching the accuracy of an NDA system are being considered such as comparing to well benchmarked burnup codes. It is our hope that the research plan presented here is of interest to others. We hope to be able to collaborate with all interested parties.

The twelve NDA techniques being researched are the following: delayed gamma, delayed neutrons, differential die-away, lead slowing down spectrometer, neutron multiplicity, nuclear resonance fluorescence, passive prompt gamma, passive neutron Albedo Reactivity, self-integration neutron resonance densitometry, total neutron (gross neutron), X-ray fluorescence, ^{252}Cf interrogation with prompt neutron detection.

Novel Technologies for the Detection of Undeclared Nuclear Activities, Materials and Facilities

In 2005, the International Atomic Energy Agency (IAEA) established a new project, *Novel Technologies for the Detection of Undeclared Nuclear Activities, Materials and Facilities,* (also known as the "Novel Technologies Project") to provide access to a wider range of safeguards-useful methods and instruments, as well as an alternative and systematic mechanism to analyze gaps in the inspectorate's technical support capabilities. Through the early identification of emerging and future inspectorate needs, particularly in the area of detecting undeclared nuclear activities, materials and facilities, the project is providing an effective pathway to timely "new" and "novel"[i] solutions in support of safeguards inspection efforts.

This section of the paper discusses the Novel Technologies Project and its main goal to develop improved methods and technologies that will further enhance the detection of undeclared nuclear activities, materials and facilities. A fundamental aspect of the Project has been the development of methods to identify, document and utilize nuclear fuel cycle (NFC) process *indicators*, which identify the presence of a particular process and *signatures* that emanate from an operating process. Gaps between identified strong indicators and signatures (I&S) and an identifiable safeguards-appropriate method by which it can be detected, or measured, represents a potential inspection capability where an effective tool can be developed or procured.

The project's outcome will be a range of novel methods and instruments that will contribute positively to the IAEA's overall objective of enhancing its current detection and safeguards implementation capabilities. The project will also provide the future technologies that will meet the challenges of new and emerging inspection regimes (e.g., state-level safeguards approaches). As with all safeguards-targeted R&D, the IAEA depends enormously on the continuing support of its member states to provide guidance, funds, resources, and expertise. Cooperation with member states remains a critical factor in ensuring the availability of effective and efficient methods in support of safeguards implementation.

Introduction

The IAEA serves as the world's foremost intergovernmental forum for scientific and technical cooperation in the peaceful use of nuclear science and technology. Established as an autonomous organization under the United Nations (UN) in 1957, the IAEA carries out programs to maximize the useful contribution of nuclear technology to society, while verifying its peaceful use. With more than four decades of verification experience, the IAEA is also the world's nuclear safeguards inspectorate, carrying out its various safeguards activities in more than 160 states, most of which have undertaken not to possess nuclear weapons, pursuant to the global Treaty on the Nonproliferation of Nuclear Weapons (NPT). Through in-field and IAEA Headquarters' verification and evaluation activities, IAEA inspectors work to confirm that states are in compliance with their respective nuclear safeguards obligations. Since the adoption of the NPT, safeguards verification, monitoring and detection equipment has evolved in three distinct phases:

From the early 1970s, methodology and instruments were developed and implemented mainly in support of verifying states' declarations. Most instruments were developed to support inspections based on materials accountancy, complemented by on-site nuclear measurements, surveillance and containment (or seals).

Following the first Gulf War in the early 1990s, the IAEA added new tools to expand its capabilities, including techniques such as environmental sampling, information analysis, export monitoring, satellite imagery, remote interrogation of safeguards monitoring equipment and improved portability for complementary access and hand-held verification instruments.

In 2004, the IAEA General Conference called on the Secretariat to examine innovative technological solutions to strengthen the effectiveness and efficiency of safeguards.[28] This move to innovative solutions has been further echoed in the IAEA Director General's call to "stay ahead of the game." To meet that challenge, the IAEA has implemented a number of measures, one of which includes the expansion of the "Safeguards Toolbox" through the identification and implementation of novel detection and monitoring techniques for the detection of undeclared nuclear activities, materials and facilities.

Successful detection of undeclared materials, facilities, and activities, on-site, nearby, or at a distance, typically depends on the identification of one or more unique attributes associated with the various processes within the NFC. These attributes have the capability of leaving a trace, or allowing some attribute to travel from the source to be detected using a suitable methodology or instrument and against a significant level of "background noise."

The Novel Technologies Project was established within the IAEA in mid-2005. Its chief aim has been the further enhancement of the IAEA's capabilities through the identification of effective methods and instruments that may be used by the IAEA to detect undeclared nuclear activities, materials and facilities. Since its inception, the project has initiated research and development in a number of technically diverse areas that are novel to the safeguards community. To date, these areas include research and development of useful safeguards tools based on laser spectroscopy, atmospheric gas sampling and analysis, nuclear magnetic resonance, optical stimulated luminescence, and antineutrino detection.[29] Others are currently under consideration.

Modeling the Nuclear Fuel Cycle

One of the project's core tasks has been an in-depth review of NFC processes, with the aim of identifying both the safeguards-useful and unique indicators that will identify the presence of a particular process and the resulting signatures that emanate from a process when it is in operation. At their most fundamental, indicators and signatures (I&S) can take the form of matter, energy, or information. Some general examples of typical I&S are given in table 1.

Table 1. Examples of some typical I&S

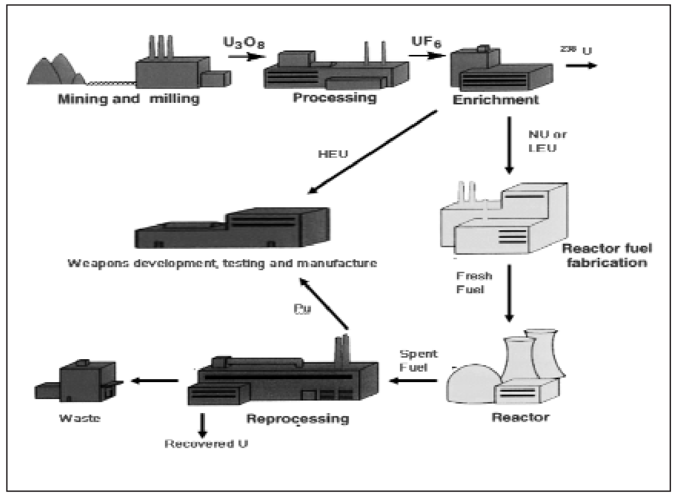
Indicators (I) *- Entities that go into making the process operative*	***Signatures (S)*** *- Entities produced by the process when it is in operation*
Resources required to establish the process	Resources required to operate the process
Unique process feed materials	Unique process product materials
Process construction materials	Process by-products and waste materials
Unique facility design features	Emanations
Open source information on related R&D, reports, papers and other available open-source information	Reports, papers and other available open-source information

Safeguards-useful I&S will be selected following reference to the relevant Department of Safeguards implementation approaches, specific verification procedures, careful modelling of a particular process, review and analysis of relevant controlled items lists, assessment of environmental sampling capabilities and limitations, carrying out in-house and open-source literature searches and discussions with experts. In addition, a "needs-pull/technology-push" approach is being taken to perform a technology gap analysis. The safeguards needs-pull will flow from the identification of I&S together with information gleaned from IAEA-sponsored expert meetings and workshops. The technology-push exists due to advances in technologies and the desire by the IAEA to assure that it employs the most effective and cost-efficient detection methods.

The NFC model developed for the project builds upon work that has been ongoing within the IAEA since the mid-1990s. A simplified NFC model, showing the major processes and including the pathways to the weaponisation stage, is given in Figure 1.

Sets of related I&S are identified by the systematic and detailed examination of each process and the various methods by which the process may be constructed and operated. Further analysis is employed to identify I&S which are both unique to a particular process and useful to safeguards as strong I&S. The information gathered by this method is archived in a specifically designed and secure database with appropriate information sharing and analytic tools.

Figure 1. A simplified model of the nuclear fuel cycle (NFC)



Defining Safeguards-useful I&S – Enrichment Example

The following example from the enrichment process is used to demonstrate the methodology to define safeguards-useful I&S. The first step is the identification of all the possible methods that may be used to enrich significant amounts of uranium. In Figure 2, three basic enrichment paths are addressed, based on the form of the feed material appropriate to the method (UF_6, UCl_4, or uranium metal).

The next step is the creation of a generic process model for the method being analyzed. For example, a generic model for enrichment, by the gas centrifuge method, can be constructed and used to identify specific component parts and materials used in the construction of a facility, and the possible products and by-products that result from the facility's operation. Figure 3 is a

Figure 2. Three basic enrichment paths and associated methods

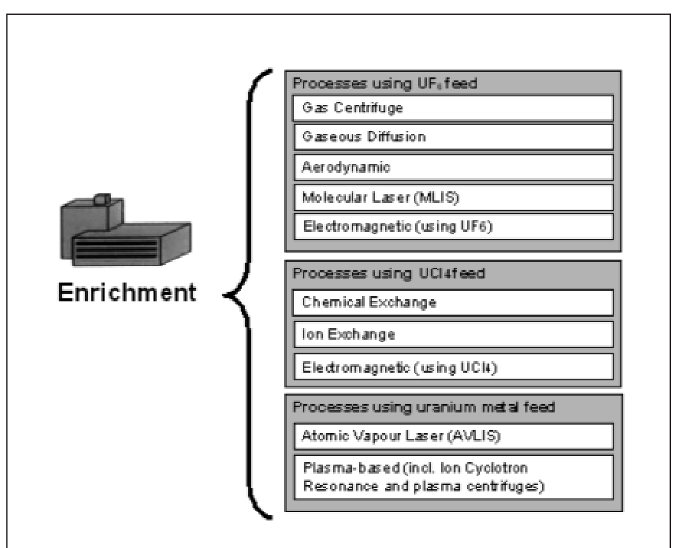


Figure 3. A notional and simplified example of a generic process model for a gas centrifuge plant

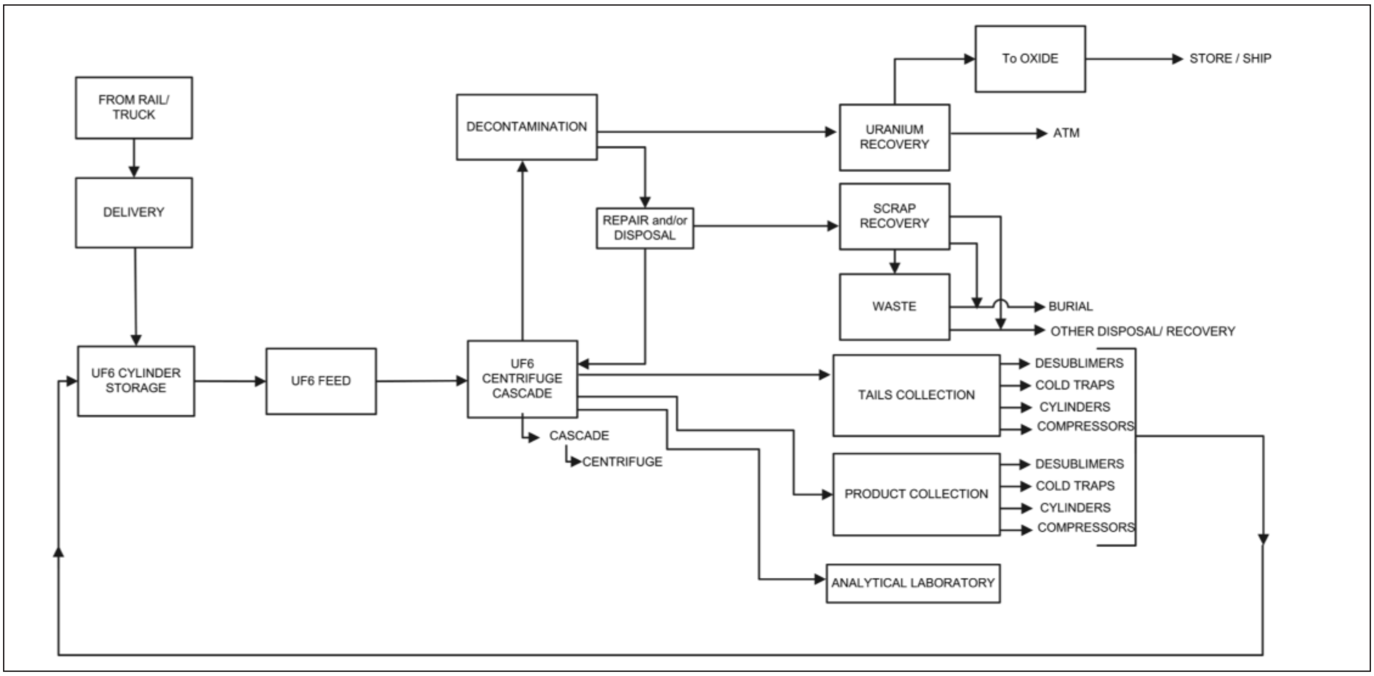


Table 2. Partial list of gas centrifuge I&S

I&S (Example)	
Specially designed equipment	Metal or composite tubes and rotor components
Nuclear materials	Natural or low-enriched uranium compounds
Technology /Training /R&D	Related R&D in rotor dynamics, flow visualizations Open source reports, papers, and other relevant information
End product	Depleted or enriched uranium compounds
Dual-use equipment	Special metals Vacuum systems
Other observables	Facility design (e.g., large area buildings, power systems
Non-nuclear materials	Special metals Composites Lubricants
By-products/effluents	Contaminated equipment, HF emissions, or energy emanations

notional example of a generic process model to demonstrate the different process stages with a selection of some of the various materials and other items that make the process work.

The I&S associated with each component are identified and classified as strong, medium, or weak. Once a strong indicator or signature has been identified, a gap analysis is undertaken to determine if there is already an approved safeguards detection or monitoring method or instrument available. For example, Table 2 provides a representative list of I&S that are applicable to the detection and monitoring of a gas centrifuge plant and associated activities.

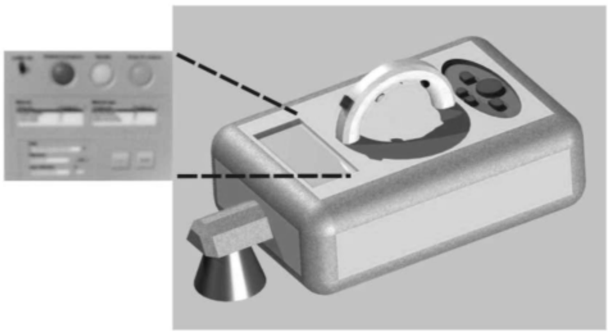
While some radionuclides are often considered to be strong I&S of particular processes, there are also many unique non-radioactive I&S materials associated with particular stages. The above method is also being used to review other critical processes of conversion, reprocessing, and reactors within the NFC.

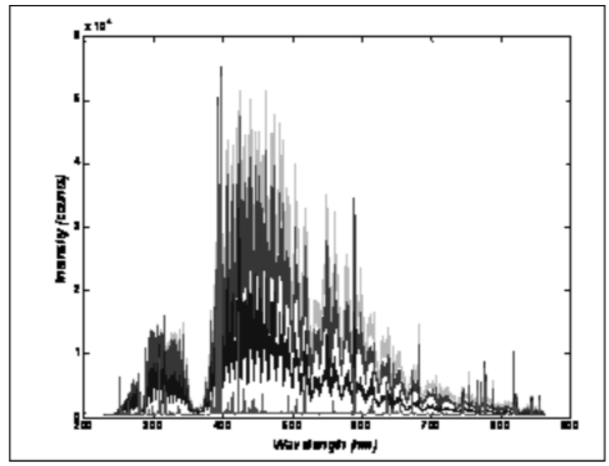
Gap Analysis

Following the identification of a strong, safeguards-useful indicator or signature and confirmation that it meets an established safeguards implementation need, a gap analysis is employed to determine if a capability exists for measurement, monitoring or detection. Where a capability does not already exist in the IAEA's "Safeguards Toolbox" as an approved method or instrument, a subsequent assessment is undertaken to determine the extent and level of research, development, evaluation, and field-testing that will be necessary to implement that capability.

The general approach outlined above has been used to initiate conceptual studies and instrument development for specific

Figure 4. *Left:* An artist's impression of a hand-held LIBS for on-site inspection activities; *Right:* Overlaying spectra from samples of yellowcake originating from different states' mines





safeguards applications. Work has already been initiated into the development of portable analytical tools based on laser-induced breakdown spectroscopy (LIBS), a forensic technique based on optically stimulated luminescence (OSL), the sampling and analysis of atmospheric gaseous emission and a proposal for an enrichment and flow monitor for gas centrifuge and diffusion plants, based on SQUID (Superconducting quantum interference device) detectors and nuclear magnetic resonance (SQUID-NMR). The following two sections describe examples of some further novel technologies currently under consideration.

On-site Detection and Analysis of I&S Compounds, Alloys, Elements and Isotopes Using Laser-induced Breakdown Spectroscopy (LIBS)

In 2005, the IAEA identified a need for improved capability for the safeguards inspector to identify unknown materials in the field in the solid, liquid and gaseous forms. Under the Model Additional Protocol (AP), a state provides information about, and allows IAEA inspector access to, all parts of its nuclear fuel cycle, including uranium mines, fuel fabrication, and enrichment plants, nuclear waste sites, and any other location where nuclear material is, or may, be present. Furthermore, the state must provide information on, and IAEA short-notice access to, all buildings on a nuclear site. When undertaking a CA inspection, a number of defined activities can be carried out under the AP. These include, *inter alia,* collection of environmental samples and utilization of radiation detection and measurement devices. It is envisaged that an appropriate portable system would be capable of being used in this circumstance to provide the inspector with immediate identification of unknown material, thereby allowing appropriate and timely modification of the inspection process to resolve any anomalies.

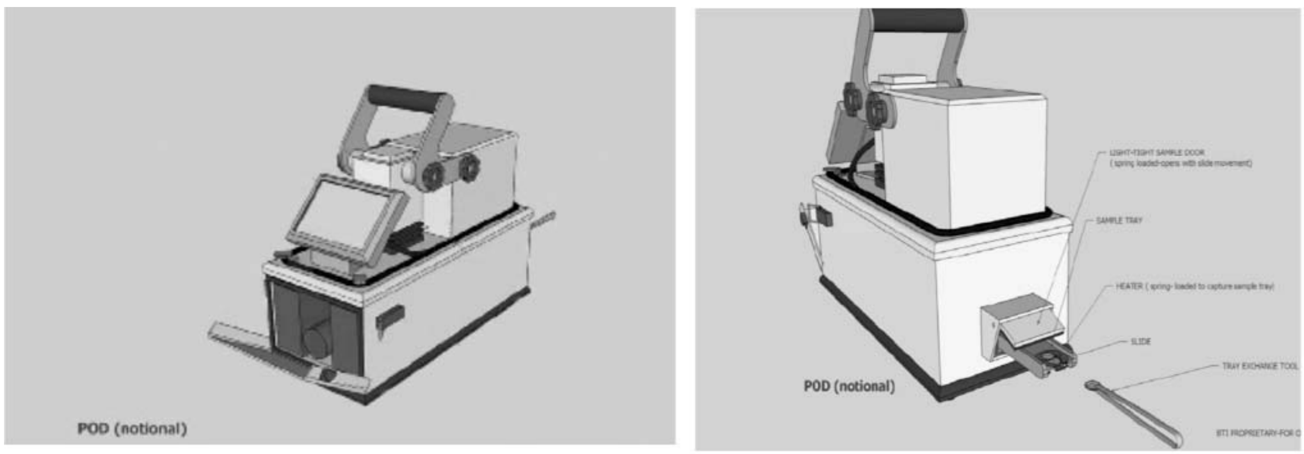
Following on from recent rapid growth in laser capabilities and affordable component availabilities, the IAEA convened a workshop on the Application of Laser Spectrometry to IAEA Safeguards in 2006,[30] with the aim of identifying laser-based techniques meeting safeguards needs. A principal recommendation of that meeting was for the IAEA to pursue the development of a novel CA instrument based on laser induced breakdown spectroscopy (LIBS) for the detection of I&S of materials strongly associated with NFC processes.

LIBS is an atomic emission spectroscopy technique, utilizing a pulsed laser that is focused on an area of interest. The laser ablates a small about of the target material forming a plasma plume above the surface of the material. The light emitted from that plasma is collected optically and resolved temporally and spectroscopically to produce an intensity versus wavelength spectra, which is compared to reference spectra in a library of known responses to allow matching to take place.

To implement the recommendation from the workshop, the IAEA undertook a task with the Canadian Member State Support Program to develop a portable LIBS system. Initial development and evaluation have proved promising with the system correctly identifying various yellowcake samples and accurately classifying their origin in tests at the Safeguards Analytical Laboratory, Seibersdorf.[31] Current efforts are focusing on the miniaturization of the technology for one-handed use and deployment of appropriate eye-safe systems. It is expected that the delivery of a pre-production version to the IAEA will take place by the end of 2009, when it will undergo field testing and modification based on user feedback.

Based on the apparent success of the technique for the analysis of a wide range of materials, a more specific workshop was convened in 2008 to discuss the user requirements for the hand-held unit, as well as possible other beneficial Safeguards applications for LIBS.[32] LIBS experts and potential end-users

Figure 5. *Left:* A front view of the production prototype OSL unit, showing the inspector interface *Right:* A rear view showing the instrument's sample port



participated and suggested two further safeguards-based applications: a laboratory scale, pre-screening system for the processing of swipe samples, and a possible future in-process monitoring system to sample and analyze materials in real time flowing in continuous process streams or stored in tanks. These two recommendations are currently under consideration for possible future tasks.

Nuclear Forensics-based Optically Stimulated Luminescence (OSL)

There is a need to further improve the IAEA's ability to determine more conclusively if a suspected location was used previously for the storage of undeclared nuclear material. To meet that need, the IAEA is currently working with the Canadian Member State Support Program to develop a portable instrument, based on the technique of optically stimulated luminescence (OSL) that can measure the radiation-induced signature stored in common building materials after radiation exposure. The technique is well understood and has, to date, gained wide use in the personal dosimeter market.[33] It works by exploiting the fact that incident ionizing radiation on a target material can excite electrons to the conduction band of the material, with associated holes remaining in the valence band. The electrons and holes drift through the target material crystal lattice until they recombine with each other or are trapped by the localized energy levels. The trapped charge-concentration provides a record of the total dose absorbed by the target material. With OSL, the process is reversed by stimulating the trapped charges back to the conduction band, which results in electron–hole pair recombination and luminescence. By measuring the luminescence, the absorbed dose of the target material can be calculated. If there is an unexpected difference between the expected and measured dose further investigation can be undertaken.

A proof-of-principle laboratory prototype was constructed and tested in Canada in October 2008 and following some design modifications, a pre-production prototype will be assembled for IAEA evaluation by mid-2009. The IAEA expects delivery of a final production unit (see Figure 5) by the end of 2009.

Atmospheric Gases Sampling and Analysis

It has been postulated that gaseous releases from some NFC processes (e.g., reprocessing) are detectable and locatable from a distance. For the IAEA to evaluate the technique for safeguards applications there is a need to understand the effectiveness of atmospheric transportation and sampling for a range of Safeguards scenarios, such as the detection of clandestine reprocessing activities. To that end, the IAEA's Novel Technologies Project has undertaken a phased approach to determine the effectiveness of this technique. A task was initiated in 2008 with the German Member State Support Program to utilize computer simulations to model the release of ^{85}Kr from a generic reprocessing plant. A number of source terms were calculated based on various possible clandestine reprocessing scenarios. The resulting emission scenarios were simulated under a variety of global weather patterns, taking into account variations in the global ^{85}Kr background and seasonal adjustments. The detection probability from each release scenario was calculated from the model and will be used in future work.[34] Figure 6 shows a computer simulated release.

The simplest application of the technique could be an onsite, or near to the site (i.e., location specific) monitor to verify the shut-down status of a reprocessing facility. In more advanced applications, there is the possibility of 'back-tracking' or tracing the origin of the sampled air by modelling the movement of air masses. It should be noted that wide area environmental sampling (WAES) has been identified as an additional strengthened-safe-

Figure 6. Example showing minimum detectable concentrations in a notional plume release. Dark filled areas indicate delectability of a 6-hour, 10 TBq release, 24, 48, and 72 hours after the event

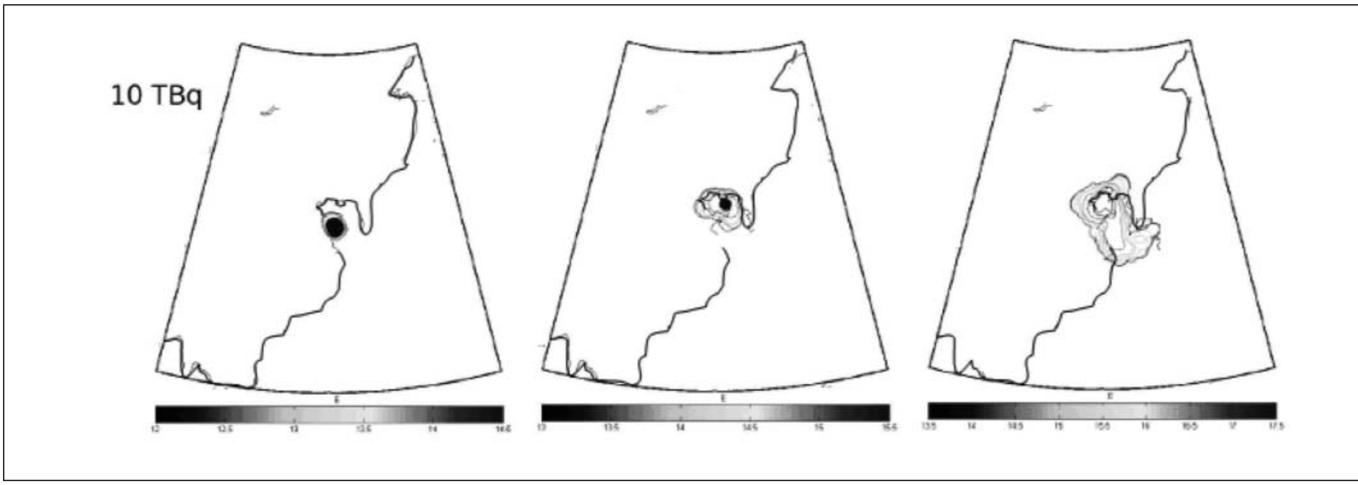
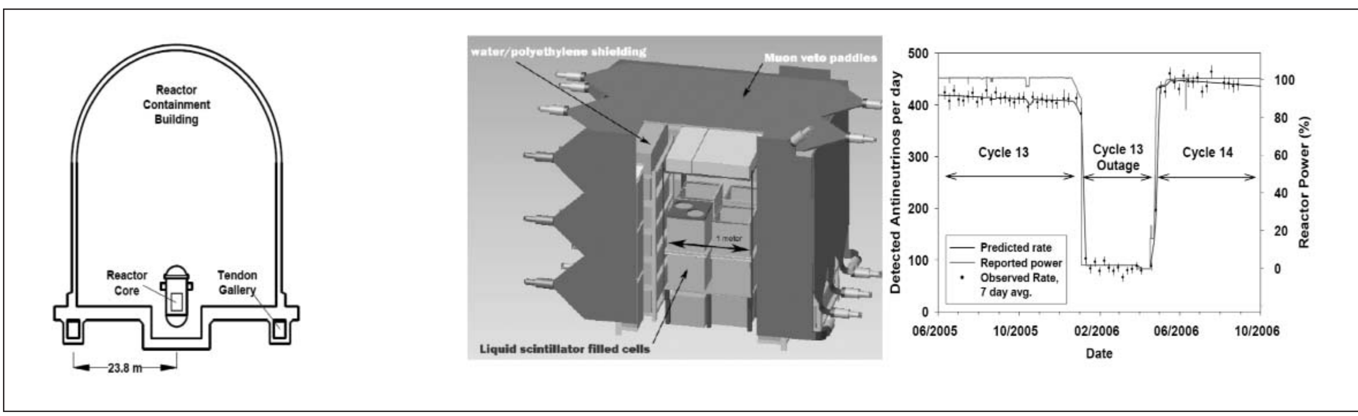


Figure 7. *Left:* A sectional view of the San Onofre nuclear power plant *Middle:* A concept for an antineutrino detector for Safeguards applications *Right:* An example of the antineutrino detection rate over the reactor's operating cycle



guards measure in the detection of undeclared nuclear activities and facilities (Article IX of the Model Additional Protocol [INFCIRC/540]). However, the implementation of WAES remains subject to approval by the Board of Governors and requires specific evaluation of sampling and procedural arrangements.

Nuclear Reactor Monitor Based on Antineutrino Event Detection and Measurement

There is a need for improved capability to determine the operating power levels of nuclear reactors that are difficult to monitor by other methods. There is also a secondary need to quantify and identify a reactor core's fuel and burnup. While other more conventional approaches are being employed currently, a novel technique based on the detection of antineutrino events in a reactor's core offers the possibility of additional features and benefits over existing methods and systems, including the ability to determine the reactor status, monitor the reactor's operational power levels and estimate the reactor core burnup and core constituents. Because antineutrinos are able to penetrate materials that can block gamma and neutron emissions, the detector can be located away from the reactor core and outside the inner radiation shields. The latter feature makes reactor monitoring far less intrusive to a facility operator and less susceptible to tampering.

To identify specific end-user needs and to gain further knowledge into possible application of the technique in solving safeguards problems, the project convened a workshop on the subject in 2008.[35] The workshop recommended further studies using computer simulation codes to assess the effectiveness of the technique for safeguarding bulk-process reactors and that it might also be useful for power and fissile inventory monitoring. While there are still a number of technical and implementation issues to be addressed, the basic principles have already been demonstrated successfully in test sites around the world. Expected development time for a safeguards version of the antineutrino detector is expected to be five or more years.

Figure 8. *Left:* A simplified diagram explaining the laser-based strand-off detection method *Right:* An artist impression of a mobile laser-based stand-off detection unit

Figure 7 shows the concept for an antineutrino detector for safeguards applications. A prototype is currently under test at the San Onofre nuclear power plant in the United States. The figure also shows the detector's relative position inside the tendon gallery and outside the reactor's radiation shield as well as an example of the antineutrino detection rate compared to the reactor's power levels over the operating cycle.

Laser-based Stand-off Detection of Gaseous Compounds

The project is currently reviewing possible methods that could be employed by the IAEA to detect undeclared processes that may be concealed. Some NFC processes emit gaseous side-products as part of their operation. Laser-based detection and monitoring of industrial and automotive effluents in the atmosphere have been routinely conducted by environmental agencies around the world. By stimulation of specific gaseous compounds in the air using wavelength tuned lasers and analysing the return light with a telescopic spectrometer, commercial systems have been developed for monitoring hydrogen fluoride (HF), hydrogen chloride (HCl), hydrogen sulphide (H2S), ammonia (NH3), methane (CH4), carbon dioxide (CO2), hydrogen cyanide (HCN), ethylene (C2H4) and acetylene (C2H2). Typical users are aluminium smelters, oil refineries, petrochemical, and chemical plants, gas production and processing, brick and ceramics manufacturing and agricultural emissions research. Detection of atmospheric effluents is possible up to kilometers from the analyser. With the identification of safeguards-useful atmospheric gaseous compounds that are unique to certain NFC processes, it would be possible to adapt laser-based detection methods and instruments to detect the effluents in the vicinity of those processes. An artist's impression of such a system is shown in Figure 8.

The Novel Technologies Project plans to continue its investigation with the participation of member states' experts. A user and expert workshop on this subject is planned for late 2009.

Other NTU Activities

As the NFC continues to evolve and expand, the IAEA will also face new challenges with respect to safeguards implementation. Appropriate methods and supporting technologies are required for recent developments, which include the verification of geological repositories, including the detection of undeclared buried structures and the future monitoring of more *fluid* reactor cores, including the pebble-bed reactor types. The Novel Technologies Unit is currently working with a number of multidisciplinary teams within the agency, investigating future NFC processes and state-level inspection approaches.

The establishment of the Novel Technologies Project has given the IAEA a new systematic mechanism to address emerging and future inspectorate needs with a wider range of methods and instruments, in addition to deriving timely novel solutions. Several promising novel technologies are already being evaluated and supported by contributing member states.

The project will increase the agency's capabilities through:

- Improved methods for verification at declared facilities
- A wider range of instruments for on-site (complementary access) and forensic-type inspections
- Enhanced capabilities for detecting undeclared activities, materials and facilities.

Conclusion

A number of technology development activities have been presented in this paper. Many other similar activities are ongoing throughout the world and will continue to be pursued to maintain the ability of the agencies charged with international safeguards to perform their mission.

Note

i. "New": Methodology that is already in use and supported by the IAEA for safeguards applications
ii. Methodology that has not been applied previously to safeguards applications

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Safeguards Technical Parameters: Directions for Evolution

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Abstract

In addressing the next steps in international safeguards, a reasonable question to ask is whether further differentiation in how states are treated in safeguards implementation could be introduced without discrimination. What reorientation of safeguards implementation could be done and how? Safeguards implementation is largely determined by the basic safeguards technical parameters, which include significant quantities, detection probabilities, timeliness goals and nuclear material types. This paper explores several possible directions for the evolution of safeguards technical parameters to be applied in future state-level information-driven safeguards, focusing on Nonproliferation Treaty (NPT) states under integrated safeguards while taking account of implementation under the other types of safeguards agreement. A reformulation of the technical objective of safeguards for NPT states under integrated safeguards is suggested. A modification of the timeliness goal for low-enriched uranium is suggested for NPT states not under integrated safeguards and for non-NPT states. Redefinitions of natural uranium and plutonium nuclear material types are suggested for NPT states under integrated safeguards. The objective of these suggestions is to stimulate consideration of introducing further differentiation in safeguards implementation for different safeguards situations without discrimination.

Introduction

In addressing the next steps in international safeguards, one starting point is that the safeguards conclusions of the International Atomic Energy Agency (IAEA) will be based on two pillars: assessment of safeguards relevant information, and results of safeguards implementation in the field. This article focuses on possible evolution of safeguards implementation in the field.

In recent years at the IAEA, routine safeguards inspections and their support have made space for increasing effort on collection, analysis and evaluation of safeguards-relevant information and on dealing with special verification cases—Iran, the Democratic People's Republic of Korea, and recently Syria. This reorientation of safeguards resources represents the direction for evolution of IAEA safeguards that is desired by external stakeholders.

As the IAEA continues to move toward information-driven safeguards, what reorientation of safeguards implementation in the field could be done and how are reasonable questions to be asked? Can further differentiation in in-field safeguards implementation be introduced without discrimination in how states are treated? An approach often mentioned is to take further account of state-specific features and characteristics in the state-level safeguards approach.

The possibility of further differentiation of the basic safeguards technical parameters has not been given much attention. These parameters, which largely determine safeguards verification in the field, include significant quantities (SQ), detection probabilities, timeliness goals and nuclear material types.

This article explores possible directions for evolving the safeguards technical parameters to be applied in future state-level information-driven safeguards. The objective is to stimulate consideration of this approach to introducing further differentiation in safeguards implementation for different safeguards situations without discrimination.

Safeguards Implementation Under Different Safeguards Agreements

The IAEA will implement safeguards for states with significantly different situations with respect to their safeguards agreements. Six situations can be differentiated.

A. Non-Nonproliferation Treaty (NPT) states with INFCIRC/66 type agreements (which may include a state-specific additional protocol), i.e., India, Israel, and Pakistan.

B. NPT non-nuclear weapon states with INFCIRC/153 type agreements (comprehensive safeguards agreements).

C. NPT non-nuclear weapon states with comprehensive safeguards agreements with an additional protocol based on INFCIRC/540. This includes two situations:
   - C.1 states for which the IAEA is in the process of drawing the 'broader safeguards conclusion' that includes that it has no indications of undeclared nuclear material or activities; and
   - C.2 states for which the IAEA has drawn the broader safeguards conclusion, opening the way for so-called integrated safeguards.

D. NPT non-nuclear weapon states with comprehensive safeguards agreements with a small quantities protocol (SQP) (which may include an additional protocol).

E. Nuclear weapon states with a state-specific voluntary offer safeguards agreement, i.e., China, France, Russian Federation, United Kingdom, and the United States.

Over the coming years, more states are expected to move through the sequence from B to C.1 to C.2. A residual number of NPT states will remain in situation B. Most NPT states will be in situation C.2, which will represent the *norm* for international safeguards. Therefore, two directions can be identified for evolution of safeguards implementation: to further increase the efficiency of safeguards in states under the safeguards 'norm; and to further strengthen as appropriate the effectiveness of safeguards implementation in NPT states in situation B, and perhaps the non-NPT states in situation A.

This article will focus on directions for evolution of what IAEA has called "safeguards measures and in-field verification activities"[1] in states under integrated safeguards (situation C.2). Implementation under INFCIRC/66 states (situation A) and in other NPT states (situations B and C.1) will also be mentioned. The type of thinking behind the ideas presented in this article could be extended to NPT/SQP states and nuclear weapon states (situations D and E).

Safeguards Technical Parameters—Directions for Evolution

In March 2002 the IAEA Board of Governors took note of the "Conceptual framework for integrated safeguards," which comprises the safeguards concepts, approaches, guidelines, and criteria that govern the design, implementation, and evaluation of integrated safeguards.[2] That conceptual framework included several changes in the basic safeguards technical parameters to be applied in states under integrated safeguards. The most notable was the change in the timeliness goal for irradiated nuclear material (see 3.3). In 2009, after seven years, this initial stage of integrated safeguards is being implemented in state-level safeguards approaches in an increasing number of states.

The Technical Objective of Safeguards

The technical objective of safeguards in NPT states was stated in the model comprehensive safeguards agreement (INFCIRC/153), developed around 1972.[3] In paragraph 28, the "objective of safeguards" was defined as:

> *"the timely detection of diversion of significant quantities of nuclear material from peaceful activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection."*

In order for the IAEA to put that objective into practice, the Standing Advisory Committee for Safeguards Implementation (SAGSI) presented in the 1970s definitions for the new term "*significant quantity*" as well as for "*timely detection*" (see 3.3 below). A significant quantity (SQ) was defined as the amount of nuclear material a state would need to obtain in order to produce one nuclear weapon.[4] Values for the SQ were defined for various types of nuclear material, e.g., 8 kg for plutonium and 25 kg U-235 for high-enriched uranium.

The IAEA adopted SAGSI's proposals for significant quantities. Over the years, the SQ values have been questioned, in particular regarding whether the IAEA should use smaller SQ quantities to take account of sophisticated weapon technology. That discussion will not be taken up here; rather the question is raised whether the *plural* formulation (*significant quantities*) in paragraph 28 of INFCIRC/153 should be applied in some cases.

In the 1970s the IAEA decided to implement the SQ as the *goal quantity* in its verification of declared nuclear material. What this means is that the IAEA decided to aim to detect the diversion of the amount of nuclear material needed for one nuclear weapon. It is suggested to revisit that decision.

What assumption should IAEA make for the amount of bomb material a state, which decided to clandestinely develop nuclear weapons while under IAEA safeguards, would set as its initial weapons material production goal? The quantity needed for one weapon is clearly the minimum, and that is what IAEA has used in its technical implementation of safeguards in all states. Might that be more conservative than appropriate in some cases? Are there any historical precedents that might serve as guidance? The answer is yes. One is the South African program, which produced material for six weapons as its initial goal. A number near that is often quoted for North Korea.

Would it be reasonable for the IAEA to differentiate its safeguards technical objective according to the different safeguards agreement situations of states? For states for which the IAEA has drawn the broader safeguards conclusion that all nuclear material in the state remains in peaceful uses, *what about using a goal of detecting diversion of the nuclear material needed for several nuclear weapons, e.g., 3 SQ,* while maintaining the goal of detecting diversion of the nuclear material for one weapon (one SQ goal quantity) for other states (other NPT non-nuclear weapon states, non-NPT states, nuclear weapon states)?

To develop how this idea might be implemented, consider two options for expressing the IAEA technical objective in NPT states under integrated safeguards:

- *A good (e.g., 50 percent) probability of timely detection of diversion of significant quantities of nuclear material; versus*
- *A low (i.e., 20 percent) probability of timely detection of diversion of a significant quantity of nuclear material.*

The impact of adopting the first of these on safeguards implementation would be small, but it would result in some redirection of safeguards verification effort away from facilities with small amounts of nuclear material.

Detection Probabilities

To evaluate the two options presented above, it is necessary to consider the parameter *detection probability.* If diversion of a given amount of nuclear material has occurred, the safeguards activities performed by IAEA to detect such a diversion have a certain probability of succeeding, i.e., a detection probability. The IAEA sets target detection probabilities for detecting the absence of a goal quantity of nuclear material (to date, 1 SQ). These range from 100 percent down to 10 percent detection probability, depending on several factors, primarily on the nuclear material category but also on the type of safeguards agreement. For practical application, IAEA uses primarily three detection probabilities—*High* (90 percent); *Medium* (50 percent); and *Low* (20 percent).[5]

For NPT states with comprehensive safeguards agreements, the target detection probabilities were set in the 1970s as follows:

- For unirradiated direct-use nuclear material (separated plutonium, HEU), *High* detection probability for accountancy verification of the material balance (physical inventory verification [PIV] and nuclear material transfers);
- For other nuclear material (irradiated direct-use nuclear material and for indirect use material), *Medium* for accountancy verification of the material balance.

For NPT states under integrated safeguards, it was decided that detection probabilities would be maintained at *high* for separated plutonium and HEU, but for other nuclear material would be one step lower than in NPT states with comprehensive safeguards agreements alone, with *low* being the minimum. On that basis, the detection probabilities to be used in integrated safeguards were set around the year 2000 as follows:

- For unirradiated direct-use nuclear material, *high* for accountancy verification of the material balance;
- For other nuclear material (irradiated direct-use nuclear material and for indirect use material), *low* for accountancy verification of the material balance.

This explains the low detection probability in the second option in 3.1.

For safeguards under INFCIRC/66-type safeguards agreements, it was decided in the 1970s to set detection probability requirements one step higher than for comprehensive safeguards agreements, and this has been maintained.

Timely Detection

The concept of timely detection was introduced in the development of the model comprehensive safeguards agreement (INFCIRC/153) also in paragraph 28 (see 3.1 above), with the objective of "the timely *detection* of diversion." In order for the IAEA to put that objective into practice, SAGSI presented a definition of *detection time* as the maximum time that may elapse between diversion and its detection by IAEA safeguards, and proposed detection times based on the *conversion times* required to convert different forms of nuclear material to the metallic components of a nuclear explosive device.

The IAEA then specified *timeliness goals* for different categories of nuclear material, taking into account detection times, facility practice, available equipment, and inspector resources. These were established as:[6]

- one month for unirradiated direct-use nuclear material;
- three months for irradiated direct-use material; and
- one year for indirect-use material.

In setting the implementation requirements for integrated safeguards in 2001, the IAEA decided to maintain the timeliness goals except for irradiated direct-use material, which was changed from three months to one year. This extension of the timeliness goal for spent fuel was based on a reassessment of the initial conditions used in setting the conversion times, namely that all necessary conversion (including spent fuel reprocessing) and manufacturing facilities exist in the state, that processes have been tested, and that non-nuclear components of the device have been manufactured, assembled and tested. With the expanded information and access in a state under an additional protocol, together with expanded information collection and enhanced analysis, the IAEA decided to assume that it would have a reasonable probability of detecting the existence of such preparatory activities, and therefore, a timeliness goal of one year could be applied in such states under integrated safeguards.

Technical advances in uranium enrichment technology, in particular in centrifuge enrichment, together with wider availability of that technology, have raised the question of shortening the timeliness goal for low-enriched uranium (LEU). It is currently one year based on the conversion time for gaseous diffusion uranium enrichment. A relatively small number of centrifuges could enrich LEU up to weapon usable enrichment in a matter of months. In states where the IAEA has a reasonable chance of detecting preparations for centrifuge enrichment, continuing the one year timeliness goal for LEU may be defensible. *For other NPT and the non-NPT states, would it be reasonable to reduce the timeliness goal for LEU from one year to three months?*

Nuclear Material Types

Since the 1970s, IAEA safeguards implementation has been based on setting specific verification requirements for the following types of nuclear material:[7]

- High-enriched uranium, HEU (20 percent or more enrichment in U-235),
- Low-enriched uranium, LEU (less than 20 percent enrichment in U-235),
- Natural uranium (0.71 percent enrichment in U-235),
- Depleted uranium (less than natural enrichment),
- Plutonium (any isotopic composition); and
- Uranium-233 and thorium.

Over the years, proposals have been made to modify several of the definitions of those nuclear material types. Two will be discussed here.

Natural Uranium
When spent fuel from light water nuclear power reactors is reprocessed, the enrichment of recovered uranium is in the range 0.9 - 1.5 percent. Such recycle uranium also contains more minor uranium isotopes (U-232, U-234, U-236). There has also been consideration of using slightly enriched uranium in advanced heavy water power reactors, in the range 0.9 - 2 percent enrichment.

Recycle uranium, according to the material type definition above is considered as low-enriched uranium. The same would be true for slightly enriched uranium. Consequently, IAEA applies more intensive verification on such uranium than it does on natural uranium. This can be justified by the reduced separative work required to obtain weapon grade uranium: a reduction of 18 percent for uranium of 1 percent, 26 percent for 1.2 percent, and 35 percent for 1.5 percent enrichment, compared to natural uranium.

Nevertheless, the question can be asked, *would it be reasonable in NPT states under integrated safeguards to extend the natural uranium type, either to 1.5 percent, or perhaps to 1.2 percent or 1 percent?* The impact of adopting such a change on safeguards implementation would be small, but it would result in some redirection of safeguards verification effort away from less sensitive to more sensitive nuclear material.

Plutonium
IAEA safeguards concentrates on "direct use material," which is nuclear material that can be used for the manufacture of nuclear explosive devices without transmutation or further enrichment. Direct use nuclear material includes plutonium containing less than 80 percent Pu-238.

The fact that the presence of Pu-240 (and other plutonium isotopes) makes it more difficult to use plutonium in a nuclear weapon is well known. On that basis, there have been proposals over the years for safeguards implementation to distinguish plutonium by its Pu-240 content and apply less intensive safeguards to plutonium with higher Pu-240 content. An important paper titled "Proliferation Aspects of Plutonium Recycling" was published in the *Journal of Nuclear Materials Management* in 2002.[8]

This subject has come up in the international programs addressing advanced nuclear systems. A survey of studies and reports, including work from the GEN-IV International Forum (GIF) and IAEA, was recently published as a contribution to the GIF Proliferation Resistance and Physical Protection Working Group.[9] *"Unattractive isotopic composition of plutonium in discharged fuel"* is considered to be one proliferation resistance intrinsic feature.

Those publications indicate the complexity of this matter. Consideration of several plutonium types has been proposed, considering Pu-240 content or Pu-238 content. That this topic is of current interest is demonstrated by the two papers presented at the 2009 INMM Annual Meeting.[10,11]

In line with the ideas presented in this paper and focusing on near term safeguards implementation, the question can be raised: *Would it be reasonable in NPT states under integrated safeguards to extend the definition of plutonium to two or more types with different verification requirements?*

Further Possibilities for Differentiation Without Discrimination
Reasoning similar to that presented above could be applied to other verification requirements to identify additional directions for further differentiation without discrimination. In particular, it would be useful to consider facility-type specific requirements, such as for LWR spent fuel pond surveillance, coverage of pin diversion, activities at small research reactors, and verification of transfer of spent fuel to dry storage. While exploring those is beyond the scope of this article, the application by the IAEA of differentiation without discrimination to containment and surveillance will be discussed as a good example.

Containment and surveillance are *important complementary measures* to nuclear material accountancy.[12] The application of containment/surveillance (C/S) measures is aimed at verifying information on movement of nuclear or other material, devices and samples or preserving the integrity of safeguards relevant data.[13] In many instances C/S measures cover the periods when the inspector is absent. C/S measures are applied to extend the validity of previous measurements and thereby reduce the need for repeating measurements on previously verified items. This use of C/S measures is termed *maintaining continuity of knowledge.*

Nuclear material covered by C/S measures must, of course, be verified. IAEA has set requirements, which include appropriately verifying the nuclear material prior to placement under C/S, periodically evaluating the C/S measures applied (e.g., reviewing the surveillance record and/or verifying the integrity of applied seals) and examining the integrity of the containment. When the C/S measures are evaluated and the containment is examined with positive results, verification of the nuclear material under C/S is performed at a reduced level of measurement. This is done in recognition that C/S measures are not perfect. It termed *remeasurement* to distinguish it from the full *reverification* that is performed before application of C/S and if C/S evaluation is not positive.

For light water power reactors (LWRs), the remeasurement requirement for spent fuel under C/S was set in the 1970s as verifying the spent fuel for gross defects with 10 percent detection probability during the annual PIV.[5] Under integrated safeguards, IAEA decided to place more confidence in the C/S measures and reduce the frequency of that remeasurement. To maintain the deterrence effect for a verification that does not take place every year, the requirement can be stated as remeasurement on the average once every three years during the annual PIV. This reduced reverification requirement is a good case of differentiation without discriminating for NPT states under integrated safeguards.

Summary of Proposals for Evolution of

Safeguards Technical Parameters

Several directions for evolution of safeguards technical parameters have been presented in this article, focusing primarily on NPT states under integrated safeguards while taking account of implementation under the other types of safeguards agreement. Before their adoption, further justification and discussion of the ideas presented would be needed. The intention here is to stimulate consideration of using this approach as a way to further differentiate without discriminating in future efforts to improve the efficiency while maintaining, or strengthening as appropriate, the effectiveness of IAEA safeguards.

The proposals addressed in this article, which are related to the safeguards technical objective, to timeliness goals, and to definitions of nuclear material categories, would result in changes in in-field safeguards implementation in states depending on the status of their safeguards agreement. In summary, the proposals are as follows.

Safeguards technical objective

The IAEA has to date interpreted the *technical objective of safeguards* as stated in INFCIRC/153, paragraph 28 to mean detection of the diversion of the amount of nuclear material needed for one nuclear explosive device. This interpretation has been applied uniformly as the detection goal in safeguards implementation under all types of safeguards agreements.

In specifying safeguards requirements for NPT states under integrated safeguards, the IAEA has introduced differentiation without discrimination by reinterpreting the safeguards technical objective in a way that can be summarized as achieving a lower probability of timely detection of diversion of the nuclear material needed for an initial nuclear explosive device.

Recalling that the INFCIRC/153 objective is stated as *"the timely detection of diversion of significant quantities of nuclear material,"* it is suggested that an alternative approach to differentiation for NPT states under integrated safeguards would be to interpret the technical objective as: *"A good probability of timely detection of diversion of significant quantities of nuclear material"* (i.e., the nuclear material needed for several nuclear weapons). The impact of such a change on safeguards implementation would be small, but it would result in some safeguards verification effort being redirected away from facilities with small amounts of nuclear material.

Timeliness goals

The IAEA has used the same *'timeliness goals'* for implementation under all types of safeguards agreements, with different values for different categories of nuclear material:

- one month for unirradiated direct-use nuclear material (HEU, plutonium);
- three months for irradiated direct-use material (spent fuel); and
- one year for indirect-use material (low-enriched, natural, depleted uranium; thorium).

To increase differentiation without discrimination in safeguards implementation, the IAEA has reinterpreted the timeliness goal for spent fuel in NPT states under integrated safeguards as one year, instead of three months.

Regarding the timeliness goal for low-enriched uranium (LEU), technical developments in uranium enrichment, especially centrifuge enrichment, have reduced the time that would be needed to enrich LEU up to weapons grade enrichment. To differentiate without discriminating between states under different safeguards agreements, it is suggested retain a one year LEU timeless goal for NPT states under integrated safeguards but to reduce the LEU timeliness goal to three months for NPT states not under integrated safeguards and for non-NPT states.

Nuclear material types

IAEA safeguards implementation is based on setting verification requirements by type of nuclear material. Two of these are:

- Natural uranium (0.71 percent enrichment in U-235), and
- Plutonium (any isotopic composition).

When uranium recycled from reprocessing, which has enrichment in the range 0.9 - 1.5 percent, is used, it considered by IAEA as low-enriched uranium, with consequently more intensive verification is applied than for natural uranium. It is suggested that a reasonable differentiation without discrimination would be to broaden the definition of the natural uranium material type to include uranium above natural enrichment, up to 1 percent, 1.2 percent or 1.5 percent, for NPT states under integrated safeguards.

The presence of Pu-240 makes plutonium more difficult to use in a nuclear explosive device. How this should be taken into account in advanced nuclear systems is currently in discussion. Regarding differentiating without discriminating in safeguards implementation, it is suggested that consideration be given to by extending the definition of plutonium to two or more types (based on Pu-240 or Pu-238 content) with different verification requirements in NPT states under integrated safeguards.

Reasoning similar to that presented in this article could be used to identify other areas for differentiation without discrimination in safeguards implementation requirements in states with different safeguards agreement situations. Areas suggested for consideration are containment and surveillance, LWR spent fuel pond surveillance, coverage of pin diversion, activities at small research reactors, and verification of transfer of spent fuel to dry storage.

The suggestions made in this article are intended to stimulate consideration of how safeguards efficiency could be improved while safeguards effectiveness is maintained, or strengthened as appropriate, by introducing further differentiation in safeguards implementation for different safeguards situations without discrimination.

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The Next Generation Safeguards Initiative (NGSI)

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U.S. President Barack Obama has stated that his administration is committed to strengthening the International Atomic Agency (IAEA) by seeking to "ensure that the agency gets the authority, information, people, and technology it needs to do its job"[1] of verifying states' compliance with obligations under the Nuclear Nonproliferation Treaty (NPT). In his April 1, 2009, London joint statement with Russian President Dmitri Medvedev, President Obama pledged to "support the activities" of the IAEA and stressed the "importance of the IAEA Safeguards system." Building on this theme, in his April 5, 2009, speech in Prague, President Obama added, "We need more resources and authority to strengthen international inspections."

The National Nuclear Security Administration's (NNSA) Office of Nonproliferation and International Security is working to support these goals through the Next Generation Safeguards Initiative (NGSI). The aim of NGSI is to revitalize the national laboratories' safeguards technology and human capital base so the United States can more effectively support the IAEA and ensure that it meets the current and emerging challenges to the international safeguards system.

While NGSI has a U.S. domestic focus, its underlying purpose is international; we recognize that this initiative cannot succeed as a purely domestic effort. Rather, our effort is intended to serve as a catalyst for a much broader commitment to international safeguards in partnership with the IAEA and other countries. Only by combining U.S. technical and scientific assets with the resources of international partners will we all be able to keep pace with the emerging safeguards challenges.

Importance of IAEA Safeguards

The international safeguards system is a central pillar of the nuclear nonproliferation regime, and the entire global community has a major stake in maintaining its effectiveness and credibility. IAEA safeguards are the primary international mechanism to monitor nuclear activities and serve as the basis for verification of states' commitments under the Nuclear Nonproliferation Treaty (NPT) as well as other safeguards commitments voluntarily undertaken by states worldwide. The application of international safeguards promotes international confidence in peaceful uses of nuclear energy, deters and provides early warning of incipient nuclear weapon programs, and establishes a mechanism for member states to make judgments regarding compliance through the IAEA Board of Governors and the UN Security Council.

With its unique access to nuclear facilities and information, the IAEA is in a critical position to reassure countries that their neighbors are not diverting nuclear material from peaceful purposes to nuclear weapon programs and, thereby, promote confidence and reduce international and regional tension. A robust IAEA capability to verify peaceful activities and to detect clandestine programs can reduce states' incentives to develop nuclear capabilities as a strategic hedge against an uncertain future. By the same token, confidence in the IAEA safeguards system will help to encourage the supply of reactors and fuel, thereby helping to meet states' energy requirements.

The IAEA's Mission is Expanding Faster than Its Resources

Today, however, the international safeguards system is under more strain than at any point in its fifty-year history, due not only to recent high-profile investigations in Iran, North Korea, and Syria, and illicit nuclear procurement networks, but also due to the rapidly expanding day-to-day activities including the important new mission in India.

Over the last twenty-five years, the amount of highly enriched uranium (HEU) and separated plutonium under IAEA safeguards has increased by a factor of ten. Moreover, the fundamental role and function of safeguards has evolved from a primary emphasis on nuclear material accountancy of declared materials to include an increasing emphasis on conducting state-level evaluations to uncover undeclared activities.

With the recognition after the 1991 Gulf War that the IAEA must not only verify *declared* nuclear material, but also seek to verify the absence of *undeclared* nuclear activities, the agency's responsibilities for collecting, analyzing, and archiving information have increased exponentially. The volume of data from environmental samples, commercial satellites, and open source documents is expanding fast. The number of states with Additional Protocols in force has risen steadily—about fifteen-fold over the last ten years—allowing for greater access to those states' nuclear programs but also bringing corresponding reporting requirements that increase the agency's workload. Largely as a result of these developments, the IAEA has estimated that it will need to increase its "desk evaluation" activities at headquarters by up to 50 percent by 2030.[2]

Despite its expanding workload, the IAEA regular safeguards budget has remained essentially flat in real terms for nearly two decades,[3] and more than a third of senior IAEA staff are expected to retire by 2011[4] and more than half by 2013.[5] Fewer than 20 percent of the IAEA's safeguards inspectors are younger than 40.[6]

At the same time, there has been an information and digital revolution, and new technologies to collect, transmit, analyze, archive, and retrieve data continue to change rapidly. The technology for the measurement of nuclear material also continues to evolve and improve, and the IAEA is hard-pressed to keep pace with the changing technologies.

If current trends continue, strains on the system will inevitably worsen. The anticipated renaissance for nuclear power is expected to be significant given growing concerns surrounding fossil fuel dependency and global climate change. This expansion could entail the deployment of new types of reactors and large-scale, complex facilities for enrichment and fuel fabrication, interim spent fuel storage, spent fuel processing, and long-term waste storage. Much of this growth could come in developing parts of the world where risks of terrorism and proliferation, although by no means confined to them, cannot be ignored.[7]

As nuclear energy expands, proliferation challenges will continue to evolve. In particular, countries may exploit renewed interest in peaceful nuclear energy and pursue uranium enrichment or reprocessing capabilities to create an option to "break-out" of their nonproliferation commitments, if their security environment erodes. As ownership of the nuclear fuel cycle shifts from governments to commercial entities and as globalization enhances nuclear technical capability around the world, many new opportunities will arise for clandestine proliferation networks to acquire and transfer sensitive nuclear equipment and technology.

The convergence of these factors in recent years has challenged the IAEA's ability to carry out its safeguards mission effectively. Without a large-scale effort to address this requirement in the near future, the effectiveness and therefore the credibility of the IAEA's safeguards system may begin to significantly erode.

Next Generation Safeguards Initiative (NGSI)

To meet the challenges posed by this expanding safeguards mission and changing international security environment, the IAEA must have the resources necessary to perform its mission.

The United States is the largest contributor to the IAEA regular safeguards budget, provides the largest voluntary contribution, and sponsors more tasks through its member state support program than any other member state. Experts at the U.S. national laboratories have developed much of the safeguards technology that the IAEA currently uses. The United States annually provides ten to fifteen full time cost free experts (CFEs),[8] primarily from the national laboratories, and conducts a variety of technical training programs.[9] As such, U.S. leadership is critical to the strength of the international safeguards system.

An October 2007 NNSA study found, however, that U.S. investments in safeguards technology and our human capital base have been declining in recent years and that immediate action is required to sustain the necessary level of technical support to the IAEA that we have provided in the past. It also found that safeguards technology development in the United States has become more fragmented and less well coordinated. Although the United States for years has led efforts in support of safeguards implementation and technology development, these efforts have generally benefited from research and development funded by other domestic programs (e.g., defense programs) and that specific international safeguards applications have often been *ad hoc* or in response to specific requests.

Moreover, in recent years, U.S. investment in safeguards technology has lost momentum and direction. A 2005 report by the American Physical Society stated that the U.S. government needs to strengthen and better focus its technology base for international safeguards. Specifically, the report suggested that "agencies participating in safeguards development should establish clear technology development goals in the next five years" along with a "technology development roadmap" to carry the program forward. The report stressed that improving the long-term capability of the safeguards technology base would be "essential to making meaningful progress."[10]

Revitalizing the U.S. safeguards expertise and technological capabilities will put the United States in a stronger position to provide continued support to the IAEA in the form of tools, capabilities, and expertise required for the agency to provide assurances that states are meeting their nonproliferation obligations. The United States will also be in a better position to help countries planning nuclear power programs to establish robust infrastructures needed to support IAEA safeguards.

Safeguards Resource Trends in the United States

As stated above, one of the key findings of the safeguards review was that U.S. investment in and focus on safeguards research and human capital has waned significantly in recent years. The robust domestic nuclear establishment—a foundation for much of U.S. technical support to the IAEA—can no longer be taken for granted. The number of safeguards specialists at U.S. Department of Energy national laboratories has been declining for the past decade due to redirection, retirement, and attrition, weakening the U.S. safeguards base.

It appears that the erosion of the U.S. human resources base, as well as its safeguards technology foundation, has largely been driven by two factors: the flat growth curve for nuclear energy and subsequent lack of career opportunities for a generation of engineers and scientists in peaceful nuclear energy programs, and the shifting national security priorities since the end of the Cold War.

In the 1960s and 1970s, the U.S. nuclear industry had a sufficient supply of qualified technical experts. But the early growth of the nuclear era dissipated soon thereafter. Accidents at Three Mile Island in 1979 and Chernobyl in 1986, issues associated with nuclear waste disposal, and the economic competitiveness of nuclear power contributed to the decline. Public support for nuclear power faltered, and the nuclear industry stagnated over the last two decades.

However, even as support for civilian nuclear energy declined, the Reagan administration's heavy investment in defense nuclear programs R&D in the early 1980s temporarily bolstered the U.S. safeguards technology and human resource base since many of these technology programs had applications for international safeguards as well. The overlap between international and domestic safeguards efforts was considerable, both for civil and military nuclear programs. But with the end of the Cold War, funding for these programs dropped steadily as did the expertise and funding available to support safeguards. Furthermore, after the terrorist attacks on September 11, 2001, U.S. priorities shifted and significant amounts of domestic safeguards resources were shifted to physical protection and site security improvements. The fact that the same limited pool of technical experts is drawn upon by other government agencies, competing missions within the national laboratories and throughout the nuclear security enterprise, and by the private sector entities, exacerbates the problem.

Safeguards Technology

According to the IAEA's February 2008 20/20 Vision Background Report, the budget restrictions under which the agency has been operating for the past two decades have "led to a chronic deficit in capital investment..." This lack of capital investment is another factor that has contributed to the neglect of the next generation of safeguards technology. Key among the challenges to be addressed in the future are data integration, safeguards for large throughput facilities and advanced fuel cycle facilities, and detecting undeclared material production and clandestine facilities.

With the IAEA's attention focused on addressing immediate or near-term needs, the U.S. Support Program for IAEA safeguards (USSP) currently emphasizes deployment of established technologies to meet near-term safeguards implementation needs, rather than development of new, less proven, but more advanced technologies to meet long-term safeguards challenges. This is because the USSP is designed to respond to specific requests from the IAEA for technical assistance and the IAEA's request process is based on its biennial Research and Development Plan for Nuclear Verification. With a two-year planning horizon the IAEA is not positioned to plan for long-range development. (This is currently in flux, however, due to the recent development of the IAEA's Medium Term Plan and new plans for a long-term R&D program, but the current IAEA request process is still based on the biennial R&D plan.) Even with the adoption of long-range planning by the IAEA, and a proposed increase in the USSP budget for 2010, the USSP is not expected to meet all of the IAEA's research and development needs.

NGSI Program Plans

To address these challenges, in November 2008, NNSA completed a five-year program plan for NGSI, outlining projects and goals so that we can move to practical implementation. This plan reflects our priorities and envisioned activities under NGSI, the goal of which is to strengthen the policies, concepts, technologies, expertise, and infrastructure needed to sustain international safeguards.

In September 2008, NNSA's Office of Nonproliferation and International Security hosted an NGSI working meeting in Washington that brought together experts from eleven countries and the IAEA to discuss safeguards challenges and opportunities for the twenty-first century, with a particular emphasis on reaching a common understanding of the problem and coordinating programs and plans. During this meeting many of the following five program elements from the NGSI program plan were discussed.

Strengthening Authorities and Institutions. With respect to IAEA safeguards authorities and approaches, the United States will work with the IAEA and others to promote universal adoption of safeguards agreements required by the NPT and the Additional Protocol (AP). The NNSA study found that the IAEA generally has adequate authorities to meet its safeguards mission provided that states have adopted and implemented the safeguards instruments that provide those authorities. For our part, the U.S. AP entered into force on January 6, 2009.

Through NGSI, NNSA will also assess safeguards enhancements, including, for example, opportunities for greater information sharing between member states and the IAEA, investigation of weaponization and procurement activities, and options to strengthen the state-level approach to safeguards. Improved coordination of IAEA and Nuclear Suppliers Group (NSG) activities in monitoring global nuclear commerce will also be examined.

Concepts and Approaches. NGSI anticipates the deployment of new types of reactors and fuel cycle facilities, as well as the need to use limited safeguards resources effectively and efficiently, especially in plants that pose the largest burden—specifically complex, bulk-handling facilities.

As an early step, NGSI will seek to institutionalize "Safeguards by Design" as a new approach for safeguards. Safeguards by Design is an innovative approach that has potential to advance the safeguards "state of the art" by incorporating early modeling and analysis of facility process flows, and integration of advanced measurement instrumentation and monitoring systems into facility design and construction. This approach is intended to ensure that international safeguards requirements are fully integrated with safety and operational considerations from the outset of the design process of a new nuclear facility. Safeguards by Design, which is also intended to identify facility design features that would facilitate safeguards implementation, could lead to efficiencies and could help avoid costly and time-consuming retrofits. Preliminary studies are underway, and we hope to expand Safeguards by Design into a formal, multi-year project that would eventually become a universally applied standard for new nuclear facilities. In order to advance this process, we plan to work with the IAEA and others to convene an international working group to establish criteria, best practices, and design guidelines.

The NGSI program has sponsored presentations on Safeguards by Design by national laboratory experts at the IAEA's Workshop on Facility Design and Plant Operation Features that Facilitate the Implementation of IAEA Safeguards in October 2008, and at the International Symposium on Nuclear Security in March/April 2009. NNSA has also been engaging regularly with private industry in the United States on Safeguards by Design issues.

Updating the safeguards approach for gas centrifuge enrichment plants is another priority of this effort.

Advanced process monitoring approaches are also being explored under NGSI. Consistent with the IAEA's practice of utilizing all available information in drawing safeguards conclusions, we are examining how a wide range of operations data might be used to better safeguard nuclear facilities. This approach goes beyond acquiring data necessary to support accurate material accounting and seeks to verify the operational history of the facility. Much work is needed for example to develop data requirements, and address authentication and proprietary concerns, but such techniques could increase both the effectiveness and efficiency of safeguards at complex facilities.

Technology Development. NGSI will encourage a quantum improvement in current safeguards technologies. New safeguards challenges require technological and methodological advancements, particularly material verification and detection, portable destructive assay/non-destructive assay, unattended and remote monitoring, containment and surveillance, and data integration and analysis.

Our objective is to promote new safeguards technologies to deter and detect diversion at declared facilities and to aid in the detection and investigation of suspect or undeclared activities. This includes technologies that: (1) improve the precision and speed of nuclear measurements; (2) perform real-time process monitoring and surveillance in unattended mode; (3) enable in-field pre-screening and analysis of nuclear and environmental samples; and (4) collect, integrate, analyze and archive safeguards-relevant information from all available sources.

The development of a new generation of hand-held tools is an area of particular focus. In addition to the development and enhancement of these safeguards technologies, the NNSA study suggested that mechanisms should be established to improve the communication of IAEA safeguards technology needs to the technical community and provide for the transfer of fully-developed applications to the agency.

We will also soon finalize a survey of safeguards technology development activities across the U.S. national laboratories, industry and universities, because we must know what's currently available in order to determine what else is needed. We will coordinate with the IAEA and member state support programs to improve communication between the R&D community and the customer—that is, the IAEA Safeguards Department.

Human Capital Development. To address the looming human capital crisis, NGSI is taking steps to revitalize and expand the human capital base, with programs to cover the full spectrum of current and emerging safeguard-relevant disciplines. We have taken a number of initial steps to implement our action plan to develop and educate the next generation of U.S. international safeguards specialists. We initiated two new summer courses on international safeguards issues and nonproliferation in 2008 through national lab-university partnerships, and are adding a third course, on safeguards policy, in the summer of 2009.[11] We began to fund summer student interns in international safeguards at our national laboratories in 2008, and hope to expand this program by 50 percent to 75 interns in 2009. In addition, the NGSI program will sponsor postdocs at four (or more) national laboratories this year. We are also initiating a number of new lab-university collaborations through which national lab-based international safeguards experts will work with university faculty in developing new graduate level courses on international safeguards and nonproliferation at nine U.S. universities,[12] and plan to expand this, funding permitting, in 2010. As part of this collaboration with universities, we are supporting a workshop in August 2009 for university faculty on safeguards and nonproliferation educational approaches and course design, and hope to provide budgetary support for a number of university faculty-national laboratory joint appointments.

As important as university engagement is to our program, we are also mindful that many safeguards professionals entered the field after they started their careers. Accordingly, we are supporting professional development programs at several labs to help attract and introduce early and mid-career professionals into the safeguards field. Lastly, we are following up to a conference in October 2008[13] on issues we face in recruiting strong U.S. candidates for safeguards positions at the IAEA, and then facilitating their reentry into the U.S. lab workforce when they return, with an enhanced program to recruit and prepare U.S. candidates for safeguards employment at the IAEA.

Complementing these U.S.-focused efforts are a number of activities for engaging with our international partners in addressing what are common challenges in developing the next generation of international safeguards experts. Training and education, and in particular regional programs and exchanges of experts, practitioners, and students will therefore play an important role in building safeguards expertise. We are considering ways to encourage regional groupings of countries to serve as clearinghouses for information, training materials and cooperation.

Infrastructure/International Engagement. NGSI will work with the IAEA and international partners to develop a safeguards-conscious nuclear infrastructure, especially among states with limited nuclear power programs or those expressing interest in such programs.[14] The IAEA milestones process will help advance such a culture, as will linking safeguards with safety and security, as set forth in the 3S concept introduced by Japan and endorsed recently by the G-8. To this end, we plan to expand training programs for nascent nuclear powers to promote and strengthen State Systems of Accounting and Control (SSACs), legal regulatory frameworks, best practices for nuclear safety and security, and implementation of the Additional Protocol.

At the NGSI International meeting in Washington in September 2008, participants emphasized the need for coordination among states that provide assistance, as well as those that receive it, to ensure consistency of message and goals and to avoid duplication of effort. Suggested actions included a resource survey in coordination with the IAEA to determine needs, development of standardized guidance for national legislation and training materials, and organizing assistance on a regional basis.

Just as the nuclear industry has worked to develop a "culture of safety," we will seek to develop a "culture of safeguards." Through NGSI, we will work with our international partners and industry to demonstrate that nuclear safeguards are not a burden to endure, but rather a means to build confidence in the reliability, safety, and security of nuclear energy, and ultimately in the best interest of both states and industry.

As part of the nuclear renaissance we are seeing an increasing number of partnerships among countries in nuclear commerce. The common theme underlying this cooperation is that countries should partner to share the economic benefits of peaceful nuclear energy without increasing the risk of nuclear proliferation. NGSI will foster engagement with other countries.

NGSI's success will be determined in large measure by our ability to attract partners and promote collaboration. We are considering ways to share facilities to test safeguards technologies and techniques, share research and field trials, engage industry and the technical community, promote information exchanges and best practices, and work together to ensure safeguards authorities are used to their fullest.

Conclusion

IAEA safeguards challenges will only worsen if they are left unaddressed. The costs of complacency and inaction are unacceptable. We cannot sit by idly and accept the status quo. We must be proactive and address critical needs before a crisis occurs. Should we fail to adequately address the proliferation dimensions of the impending nuclear renaissance, renewed interest in nuclear energy will falter, as will the public support needed to sustain its expansion.

U.S. leadership is critical in bringing together international partners in a comprehensive and concerted effort to revitalize international safeguards. The IAEA must have the best staff, technology, operations and methodologies available, as well as adequate funding and authority. U.S. efforts should be clearly focused on this goal of providing the IAEA with the tools and resources it needs to accomplish its mission.

It will be essential for the United States to reinvigorate its own technical and human resource base to meet emerging international safeguards requirements and to engage the IAEA and international partners on new policy initiatives. We will need major new investments in technology and human resources, a new international norm to incorporate safeguards into the design phase, and improved agency communication with the private sector engaged in nuclear commerce. Technological and methodological advancements are not answers in themselves but must be accompanied by legal and institutional measures and backed by a high degree of political will.

Meeting the safeguards challenge will also involve engaging emerging nuclear countries to ensure the development and implementation of sustainable nuclear safeguards and security-conscious infrastructure, and the provision of assistance in the responsible management of new and expanded nuclear energy programs. This process involves developing new safeguards technologies, rebuilding the human resources base, strengthening international nonproliferation partnerships and promoting nuclear safety and security best practices worldwide. With such efforts we can forge a robust international safeguards culture.

We may face serious consequences if we fail to meet these challenges, but if we take the initiative and seize the opportunity, we could succeed in contributing to a more peaceful and prosperous world for future generations.

The views expressed in this article are those of the author and do not necessarily reflect those of the U.S. government, U.S. Department of Energy, or the National Nuclear Security Administraiton.

Notes

1. See www.whitehouse.gov, under the Homeland Security Agenda item; During his April 6, 2009, luncheon address to the Carnegie Endowment's Annual Conference in Washington, DC, Deputy Secretary of State James Steinberg said, "We should explore means of augmenting the IAEA's safeguards authorities, and the agency should receive the increased resources it needs to carry out its rapidly growing responsibilities."
2. IAEA. 2008. *20/20 Vision for the Future. Background Report by the Director General for the Commission of Eminent Persons*.

3. In September 2003, following fifteen years of zero real growth budget, the IAEA General Conference agreed to a one-time increase in the organization's regular budget that was phased in from 2004-2007. This included a 21.7 percent increase for safeguards. See "Report to the Board of Governors by the Co-Chairmen of the Informal Open-ended Working Group on the Program and Budget for 2004-2005," GOV/2003/48, July 16, 2003, Annex 1; see also "IAEA Safeguards: Staying Ahead of the Game," July 2007, page 19.
4. Cooley, J.N. 2008. "Building Safeguards Expertise: Projected IAEA Needs," Next Generation Safeguards Initiative Workshop, Washington, DC, September 11-12, 2008: "In the next three years, approximately 35 percent of senior staff will retire."
5. Alicia de Reynaud, head of the IAEA's Safeguards Program and Resources Office, Presentation to the NGSI Workshop on Enhanced Recruiting for IAEA Safeguards, Brookhaven National Laboratory, October 22-23, 2008. See also the Report of the Commission of Eminent Persons (CEP) on the Future of the Agency, GOV/2008/22-GC (52) INF/4, May 23, 2008, p. 29: "Half of [the Secretariat's] top management and its senior inspectors are expected to…retire in the next five years."
6. Alicia de Reynaud, Head of the IAEA's Safeguards Program & Resources Office, Presentation to the NGSI Workshop on Enhanced Recruiting for IAEA Safeguards, Brookhaven National Laboratory, October 22-23, 2008.
7. According to IAEA estimates as of September 2008, thirty-six new power reactors are under construction and "twelve countries are actively preparing to introduce nuclear power"— with up to sixty additional reactors to be built in the next fifteen years. Some projections envision global electricity generation from nuclear power plants increasing by somewhere between 25 and 95 percent by 2030.
8. To date, the United States Support Program (USSP) has provided the IAEA with more than 190 CFEs. Currently, the U.S. Support Program (USSP) is funding sixteen CFEs and nine junior professional officers (JPOs) in the IAEA's Department of Safeguards.
9. The USSP provided eighteen training courses in 2007 including courses on Non-Destructive Assay Techniques, Advanced Plutonium Verification Techniques and Safeguards at Enrichment Plants, as well as an Additional Protocol Complementary Access Exercise.
10. 2005. *Nuclear Power and Proliferation Resistance: Securing Benefits, Limiting Risk,* A report by the American Physical Society Panel on Public Affairs, May 2005, p. 10.
11. In a manifestation of strong student interest in the international safeguards field almost 100 students applied for approximately sixty total spots in the two summer safeguards policy courses. The two safeguards policy courses are run by LLNL/Monterey and Brookhaven, and the technical safeguards course is run by LANL/Texas A&M. We expect a total of almost 100 students total for the three courses.
12. The nine universities include the University of Florida, University of Michigan, University of Tennessee, University of New Mexico, North Carolina State, Georgia Tech, Washington State, Oregon State, and Washington University.
13. This is a reference to the NGSI October 22-23, 2008, Workshop at Brookhaven National Laboratory on Enhanced Recruiting for IAEA Safeguards (ERIS).
14. In his September 29, 2008, statement to the IAEA General Conference, Director General ElBaradei said that "some fifty member states have expressed interest in considering the possible introduction of nuclear power and asked for agency support."

Improving the Safeguardability of Nuclear Facilities

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Abstract

The application of a Safeguards-by-Design (SBD) process for new nuclear facilities has the potential to reduce security risks and proliferation hazards while improving the synergy of major design features and raising operational efficiency, in a world where significant expansion of nuclear energy use may occur. Correspondingly, the U.S. Department of Energy's Next Generation Safeguards Initiative (NGSI) includes objectives to contribute to international efforts to develop SBD, and to apply SBD in the development of new U.S. nuclear infrastructure. Here, SBD is defined as a structured approach to ensure the timely, efficient and cost effective integration of international safeguards and other nonproliferation barriers with national material control and accountability, physical protection, and safety objectives into the overall design process for a nuclear facility, from initial planning through design, construction and operation. The SBD process, in its simplest form, may be applied usefully today within most national regulatory environments. Development of a mature approach to implementing SBD requires work in the areas of requirements definition, design processes, technology and methodology, and institutionalization. The U.S. efforts described in this paper are supportive of SBD work for international safeguards that has recently been initiated by the IAEA with the participation of many stakeholders including member states, the IAEA, nuclear technology suppliers, nuclear utilities, and the broader international nonproliferation community.

Introduction

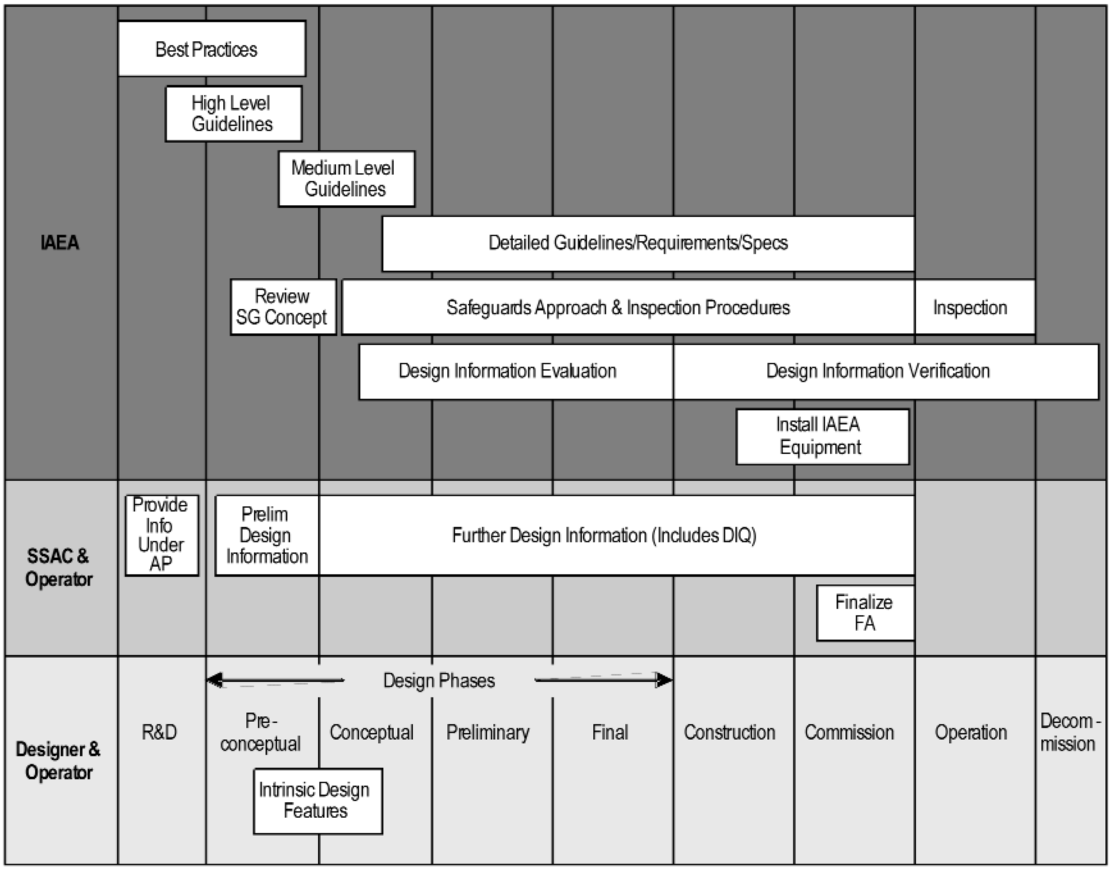
The nuclear industry has made significant operational and design advances in recent decades, notably in the area of safety. These developments, triggered by the accidents of Three Mile Island and Chernobyl reactors, resulted in nuclear energy systems that operate with impressive safety and reliability performance and in designs for future reactor systems where safety is considered as an integral part of the design process. Industry has learned that it is cost effective, from the earliest conceptual stages, to design safety into the facility. Also, since the World Trade Center attacks of September 11, 2001, increases in physical security requirements at U.S. nuclear facilities have resulted in the need for costly security upgrades, underscoring the urgency of designing future facilities to be intrinsically more secure with decreased reliance on the action of protective forces.

A design approach to cost-effectively mitigate emerging security threats as new nuclear energy systems are designed and deployed will have significant impact in a global environment of nuclear energy expansion. Proliferation resistance is defined by the IAEA as "that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material or misuse of technology by the state seeking to acquire nuclear weapons or other nuclear explosive devices." Effective IAEA safeguards are a key element contributing to proliferation resistance, in addition to other intrinsic (design) and extrinsic (institutional) features, here described as "other proliferation barriers." Safeguardability, in turn, refers to the extent to which the design of the facility readily accommodates, and facilitates, effective and cost-efficient safeguards for the facility. The proposed Safeguards-by-Design (SBD) process, described in this paper, is an approach that integrates safeguards with physical security and safety during design to improve the safeguardability of nuclear facilities.

IAEA Led International Initiative to Develop Safeguards-by-Design

The IAEA launched its exploration of the concept of Safeguards-by-Design by hosting an international workshop titled "Facility Design and Plant Operation Features that Facilitate the Implementation of IAEA Safeguards" in autumn 2008 at its headquarters in Vienna. The workshop was well-attended by participants from member states, the European Commission, nuclear industry, and the IAEA.[1] IAEA has clear responsibility to apply international safeguards, through treaties and other agreements employing monitoring and verification, while the agency's role in

Figure 1. Activities timeline for IAEA proposed Safeguards-by-Design process1



SSAC = State system of accounting for and control of nuclear material; AP = Additional protocol; SG = Safeguards; DIQ = Design information questionnaire; FA = Facility attachment.

safety and security is only advisory. Recognizing this distinction, the IAEA workshop participants focused on IAEA safeguards, in particular, when they defined a proposed IAEA SBD process as "an approach wherein safeguards are fully integrated into the design process of a nuclear facility—from initial planning through design, construction, operation, and decommissioning." The IAEA defines safeguards as "the means applied to verify a state's compliance with its undertaking to accept an IAEA safeguards agreement on all nuclear material in all its peaceful nuclear activities and to verify that such material is not diverted to nuclear weapons or other nuclear explosive devices."

SBD is expected to facilitate reaching objectives, such as: a. enhancing safeguardability in new nuclear facilities; b. reducing the time and cost for the inspectors' physical presence at facilities; c. incorporating authentication and use of process monitoring data into the safeguarding of selected nuclear facilities; d. facilitating joint-use of equipment and instrumentation between the operator and the IAEA; and e. eliminating retrofit of instrumentation needed by IAEA and increasing flexibility for future equipment installation.

The workshop participants strongly endorsed the integration of safeguards into the design of new facilities earlier than is presently done. A timeline of actors and activities was prepared to show the necessary interactions and cooperation, see Figure 1. Further workshop recommendations include: revising the IAEA Safeguards Manual to take account of the SBD initiative, providing IAEA safeguards documentation to facility designers immediately, creating several expert working groups tasked with defining the SBD process and creating an implementation strategy, developing new design guidelines organized by facility type that can be published as part of the IAEA Nuclear Energy Series, and providing general SBD process timelines for nuclear facilities in various stages, e.g., operational, evolutionary, and new design. Various beneficial design characteristics were identified which included:

- Clear safeguards vision and guidelines
- Availability of safeguards guidelines to enable compliant

and/or optimized plant to be built with minimal impact on the operator and designer/constructor
- Early integration of safeguards in the design phase to minimize impact on production, and enable easy maintenance, and unattended operation
- Detailed knowledge by operators of safeguards systems to be applied to future facilities
- Improved integration of safeguards with safety and security
- Timely advice of IAEA needs to avoid retrofitting
- Verification of signal authenticity for joint-use equipment during design information verification
- Effective stakeholder engagement in design phase minimizing changes during construction

Consistent with the proposals of the workshop, the following iterative process between the IAEA, SSAC, and facility operator is suggested in this paper for implementation of SBD. Following receipt of early design information, the agency will propose material balance areas (MBA) based on the facility design, nuclear material (NM) flows, NM composition, and the desire to meet both IAEA quantity and timeliness goals. In each MBA, both the operator and the IAEA (independently) must be able to close the material balance and evaluate any difference between the beginning and ending inventory.

The IAEA will then propose a safeguards approach that includes both key measurement and strategic points in the facility as well as the measurement/monitoring equipment to accomplish the approach. This negotiation between the three parties to finalize this approach can result in any combination of the measurement/monitoring techniques including:

- Fully independent IAEA equipment
- Joint Use Equipment whose data is shared between the facility operator and the IAEA
- Joint Use Equipment whose data is not shared and whose data set could be all collected data or some subset dependent on IAEA needs

In all cases this equipment is fully integrated into the project management system to assure all cost, schedule, and performance requirements are met including provisions for addressing authentication needs of the IAEA. Clearly all parties need to negotiate agreement to final requirements and this includes learning of and assessing potential alternate approaches that still allow independent IAEA verification but also address facility operational needs.

Safeguards-By-Design Within a National Regulatory Structure

State-level Support to IAEA

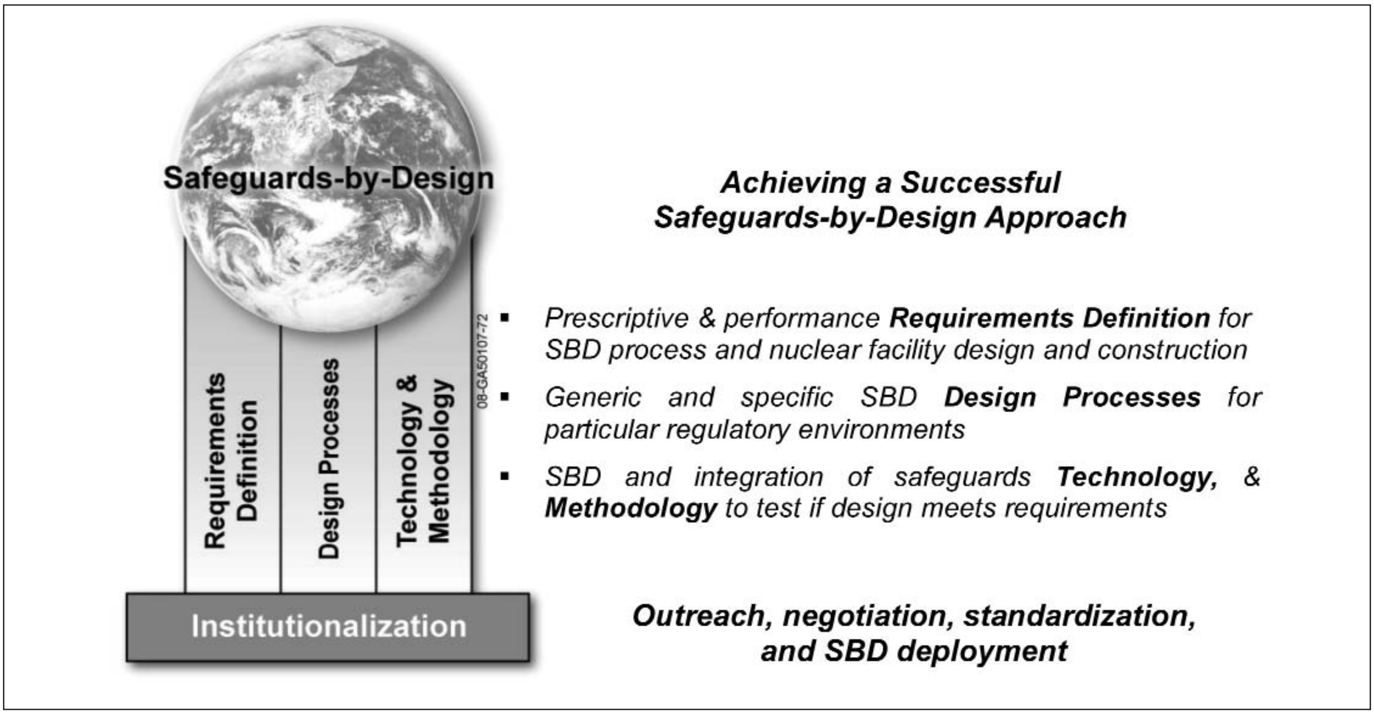
While international (IAEA) safeguards focus on the issue of nuclear material diversion by a state, requirements prescribed by a state for nuclear material control and accountancy (MC&A) and physical security defend against the threats of theft and sabotage by a non-host-state actor such as terrorists or agents of a rogue state. The nuclear material accountancy (MA), containment and surveillance (C&S), and design information verification (DIV) practiced as part of IAEA safeguards provide an independent verification of the accountancy reported by the state system of accounting for and control of nuclear material (SSAC), as well as the state actions for material control. For this reason it is vital to the IAEA SBD process that state requirements for MC&A and security also be dealt with early in the design process. Because of the close connection between state-level MC&A and physical security, and the numerous interconnections between security and safety, it becomes evident that in order to properly support an SBD process for IAEA safeguards it is necessary to include MC&A, physical security and safety in formulating and executing the overall SBD process. In other words, in order for SBD to succeed, the international safeguards effort for MA, C&S, and DIV must be fully supported at the level of domestic safeguards and security.

Next Generation Safeguards Initiative Supporting Safeguards-by-Design

Support of the SBD process is a fundamental part of the Next Generation Safeguards Initiative (NGSI) prepared by the U.S. DOE National Nuclear Security Administration (NNSA). This U.S. initiative is supportive of international efforts to develop SBD to ensure the timely, efficient, and cost-effective implementation of international safeguards, while concurrently ensuring the proper integration of national MC&A, physical protection, and safety features into future nuclear energy infrastructure. A major objective is to demonstrate and institutionalize SBD.[2]

The SBD approach requires the identification and integration of international safeguards *requirements* (in addition to national MC&A, physical protection, and safety requirements) into the design of a nuclear facility at the earliest stages of conceptual design. These requirements are high level, flexible in some aspects to enable best safeguards performance, and negotiated between the agency and the state. Once and whatever agreed, they become design requirements. Synergy in design of structures, systems, and components (SSC) provides intrinsic barriers, for example a reactor containment vessel or underground placement may help provide security against some malevolent actions as well as enhancing safety. Effective implementation of SBD avoids potentially expensive and time-consuming retrofitting of a facility during and after startup and operation. SBD also focuses on the idea that efficient design for safeguards will make it easier for an operator and state to perform satisfactory nuclear MC&A and process control, which can reap performance and cost advantages for the facility operator. Hence, good safeguards design can mean good business practice, where safeguards are designed with the goal to be integrated with facility process control rather than being added later as another layer. In this way, safeguards may

Figure 2. High-level framework to institutionalize Safeguards-by-Design



work in the background as part of a normal process and have minimal impact on facility throughput.

The NGSI also declares the importance of developing guidelines, requirements, and best practices. Institutionalizing of SBD will depend on the development of universally agreed requirements, clear guidelines, and a catalog of best practices. Guidelines and requirements would include recommendations for established safeguards systems as well as techniques and methods for particular applications or facilities.

Accordingly, the need exists to develop a simple, formalized, and integrated approach, and introduce this into nuclear facility design and construction management. Institutionalizing Safeguards-by-Design (ISBD) is the implementation of a structured approach by which international safeguards objectives, and national material control and accountability (MC&A), physical protection and safety objectives can be fully integrated by means of an SBD process into the overall design and construction process for a nuclear facility; from initial planning through design, construction, and operation. Application of SBD in the facility design and construction effort is intended to provide: early identification of safeguards requirements, inclusion of intrinsic features, optimization of facility alternatives, reduced impact to operation, minimization of life-cycle cost, and minimization of equipment retrofit.[3] International efforts to develop SBD as a standard approach in nuclear system design would enable the efficient growth of nuclear power to occur while reducing nuclear proliferation and security risks.

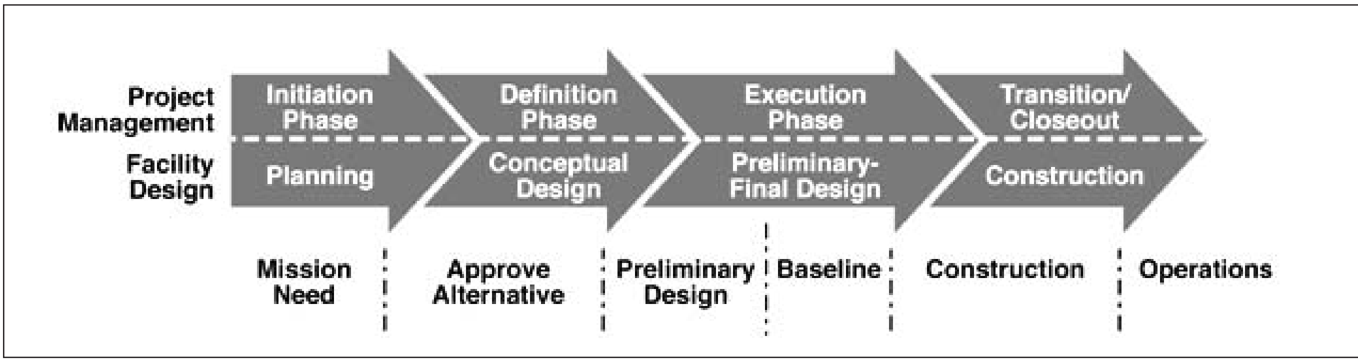
The work discussed here examined design processes, best practices and lessons learned from major design projects, developments in the integration of nuclear safety, and project and systems engineering, in order to conceptualize the framework of essential elements for SBD. This was determined to consist of the foundation of Institutionalization, which supports three technical pillars (requirements definition, design processes, and technology and methodology, all of which are addressed later in this paper) that in turn support the pinnacle of achieving a successful Safeguards-by-Design approach. Beyond the goal of institutionalizing SBD in U.S. nuclear infrastructure development and design, as illustrated in Figure 2, this work also contributes to international efforts to develop and institutionalize SBD as a global standard for the development of new nuclear energy infrastructure.

The proposed SBD process manages interaction between safeguards, MC&A, and security design and the overall design process, especially safety system and process design, to progressively develop definition and analysis at each design phase.[3, 4]

Project Management of Design and Construction

The SBD process must normally be applied within a conventional project management process, as outlined here. Most projects requiring major financial commitments are managed using formal project management procedures and processes. In the nuclear industry, project management processes for facility design and construction are based upon regulations specific to disciplines required for project and execution including technical norms, quality assurance, safety, and safeguards and security. Management of major projects is normally organized by project

Figure 3. Typical phases of project management/design[5]



phases, associated with a logical maturing of broadly stated mission needs into well-defined requirements which are converted into design and construction of a facility meeting the needs of customers such as utilities, local authorities, states, and the IAEA,[5] see Figure 3.

The project design team develops and evaluates approaches for a facility and processes that meet the project need. Feasible approaches are bounded by a set of requirements supporting the performance needed, materials and processes, areas such as environmental, safeguards, security and safety requirements, and applicable regulations. The goal is to develop an optimal approach, in terms of cost and schedule objectives, for meeting all the requirements.

Systems engineering is a valuable tool for major projects, such as nuclear facilities. It comprises technical and management processes, is an interdisciplinary field focusing on how complex engineering projects should be designed and managed, and is an effective way to manage complexity and change, and reduce cost and schedule risks. The conceptual design phase of a new system may often incur ~8 percent of the life-cycle cost, but the selected conceptual design commits ~70-80 percent of life-cycle cost.[6] This typical commitment of ten times greater cost is well known to the engineering profession and has stimulated responsive methodologies with increased emphasis on early definition of requirements, e.g., "front-end loading" (FEL) or similarly "front-end engineering design" (FEED). This illustrates the importance of the application of an SBD process where again the emphasis on early design involvement and requirements definition is all important.

Safeguards Requirements

Overview

Definition of requirements, considered broadly to include guidelines, is the first technical pillar of the ISBD framework, see Figure 2. Principal requirements for both the SBD process and for domestic and international safeguards are summarized below. Current approaches to establishing international safeguards concern mainly access to the facility and the nuclear material therein together with the performance of its monitoring and verification. By contrast, national physical security requirements tend to be deterministic and relatively prescriptive. Requirements for advanced fuel cycle infrastructure, which will have substantial differences from current infrastructure in areas such as increased use of remote handling of materials, will need to increasingly evolve toward a more performance-based framework as has occurred for safety regulation. From the facility designer's viewpoint all requirements necessary for the successful execution of SBD must be formalized, and demonstrated methodologies, (this will be addressed later in this paper), are needed to determine whether requirements are met by proposed designs. An assessment of the conceptual design to confirm that it meets, or has high assurance of meeting all requirements is essential prior to initiating later design phases. The same applies for the more detailed examination of adequacy in meeting the later, detailed, and comprehensive system requirements.

The area of guidelines and requirements is complex and dynamic, and different participants have differing needs and objectives. Requirements should be expected to evolve over time, both to address problems that may emerge with previous requirements, and also in the spirit of continuing improvement, as is the case for safety. Initially, due to institutional and technological developments always underway, guidelines, requirements and their acceptance criteria are unlikely to be fully agreed between organizations and not complete for the particular environment and facility planned. Guidelines may be negotiated at high level, e.g., between IAEA and SSAC, and turned into prescriptive or risk-informed design requirements for the specific facility by the owner/operator and/or vendor. The IAEA has criteria for safeguarding facilities and these can contribute to formulation of facility requirements. Prescriptive requirements, e.g., regulatory ones, may need interpretation for design purposes and performance requirements are often subject to commercial negotiation. The SBD process is part of the project management and design processes and is anchored by design requirements. The relationship of guidelines, requirements, and criteria merits significant further attention.

Performance Requirements for SBD Process

The objective for institutionalizing the SBD process is to provide a procedure by which international safeguards, as well as national MC&A, physical security, and safety objectives are fully integrated into the overall design and construction process for a nuclear facility, from initial planning throughout design and construction and with benefit to operation; with the goal of increasing the safeguardability, protectability and other proliferation barriers of facilities in a cost effective way. Although elements of SBD are incorporated in each phase of the project management process, the focus is on the early phases. High-level requirements for the SBD process itself (as opposed to facility performance requirements) were formulated as follows:

- Develop a simple, formalized, and integrated process for SBD that is beneficial to stakeholders
- Develop the SBD process to be flexible, consistent with and enhance the effectiveness of applicable domestic and international directives, and compliant with relevant national and regional regulatory authorities.
- Provide a useful tool for the project manager responsible for design/construction of nuclear facilities
- Base the SBD process on accepted project management, design, and systems engineering processes
- Provide safeguards and security in the facility providing maximum operational efficiency and lowest cost consistent with regulatory requirements and guidance
- Mandate a concise set of project deliverables for safeguards and security design to demonstrate a systematic, comprehensive, auditable, and transparent project design
- Develop phased safeguards effectiveness reports (akin to phased safety reports) to facilitate dialog with and acceptance by sponsors
- Initiate safeguards and security design activities in the preconceptual planning phase through the establishment of a safeguards design team including security
- Use systems engineering to integrate operability, safety, security, safeguardability, and other proliferation barriers into the facility design
- Provide early identification of intrinsic design features that enhance safeguards, safety, security, or other proliferation barriers, or assist implementation of extrinsic measures
- Mandate use of life-cycle cost (LCC) analysis as a criterion for capital expenditure decisions between intrinsic (early) and extrinsic (later) design alternatives

Prescriptive Requirements for the SBD Process

The SBD process must comply with current national regulations, agreements, directives, etc. For example in the United States, these include U.S. Nuclear Regulatory Commission, U.S. Department of Energy, U.S. Code of Federal Regulations (CFR), and other national regulatory requirements for the nuclear fuel cycle. The facility, as designed, constructed, and operated must also comply with these and other requirements. National safeguards and security often covers such areas as: a. physical protection; b. material control and accountability (MC&A); and c. cyber security. The SBD process must also comply with international agreements related to nonproliferation, particularly with requirements for the implementation of efficient and effective IAEA safeguards. Although internationally accepted methodologies for assessing designs are still in development, progress is occurring in: d. proliferation resistance including the feature of safeguardability (discussed later in this paper).

Proliferation resistance measures relate to the barriers that a proliferant state must overcome to acquire nuclear weapons through diversion from or misuse of infrastructure for nuclear energy systems. There are presently no formal national or international requirements for proliferation resistance that must be considered in design, and definition and acceptance of such requirements may take considerable time. However, the Generation IV International Forum's Proliferation Resistance and Physical Protection (PR&PP) methodology, and the IAEA-led International Project on Innovative Nuclear Reactors and Fuel Cycles, INPRO Manual—Proliferation Resistance, support the principle of including proliferation resistance in the design process.[7,8] Safeguardability is a property of the whole nuclear system and is estimated for targets on the basis of characteristics related to the involved nuclear material, process implementation, and facility design.[7] Both intrinsic and extrinsic features, including, importantly, safeguards, are included within the concept of proliferation resistance. Safeguardability, in turn, refers to the extent to which the design of the facility readily accommodates, and facilitates, effective and cost-efficient safeguards for the facility.

The proliferation resistance framework supports the SBD process by providing concepts and assessment methodologies for the quantification of the effectiveness of safeguards and security driven design in relation to lifecycle cost. This supports the iterative design process, see Figure 4.

Countries, party to the Nonproliferation Treaty (NPT), conclude a comprehensive safeguards agreement with the IAEA to cover the construction, operation, and decommissioning of their nuclear facilities. Important IAEA documents, directly related to the agreement between the IAEA and states, which have acceded to the NPT, include:

- IAEA INFCIRC/153: The Structure and Contents of Agreements Between the Agency and States Required in Connection with the Treaty on the Nonproliferation of Nuclear Weapons
- IAEA INFCIRC/274: The Convention on the Physical Protection of Nuclear Material
- Subsidiary Arrangement to the Safeguards Agreement (includes Facility Attachment)
- IAEA INFCIRC/225: The Physical Protection of Nuclear Material and Nuclear Facilities
- IAEA TECDOC-967: Guidance and Considerations for the

Implementation of INFCIRC/225, The Physical Protection of Nuclear Material and Nuclear Facilities
- IAEA INFCIRC/540: Model Protocol Additional to the Agreement(s) between State(s) and the IAEA for the Application of Safeguards

The four main elements of the IAEA facility-specific international safeguards approach, see Figure 1, are the design information questionnaire, facility safeguards approach, facility attachment, and design information verification. Under the comprehensive (INFIRC/153-type) safeguards agreement, more detailed IAEA criteria include that nuclear facilities will have, use, or permit:

- Defined "Material Balance Areas" to facilitate nuclear material accounting
- "Key Measurement Points" for measuring the flow and inventory of nuclear material
- Defined "Strategic Points" for the application of containment/surveillance and other safeguards verification measures
- Nuclear Material Accountancy based on facility operating records and state reports
- An annual Physical Inventory Taking and Verification, which is typically a complete physical inventory of all nuclear material in the facility
- Verification of domestic and international transfers of nuclear material
- An accounting process that will permit the IAEA to perform a statistical evaluation of the nuclear material balance to determine "Material Unaccounted For"
- Routine (monthly or quarterly) "Interim Inventory Verifications" for the timely detection of the possible diversion of nuclear material
- Verification of the facility design information (relevant to safeguards)
- Verification of the facility operator's measurement system (relevant to safeguards).

Safeguards inspection criteria have been developed and codified by the IAEA based on the type of nuclear facility (e.g., power plant, uranium conversion plant, uranium enrichment plant) and are summarized in the safeguards criteria section of the IAEA Safeguards Manual.[9] These criteria specify facility safeguards requirements additional to those in the Safeguards Agreement. The safeguards criteria depend on the type of nuclear material, whether irradiated or unirradiated, and closeness to direct use to produce a nuclear weapon. These facility-specific criteria must ultimately be translated into actual designed and engineered equipment and features in the facility to perform the requisite activities to the level as specified in the criteria. This poses a significant challenge to the designer in interpreting the IAEA safeguards criteria and formulating appropriate design requirements. The latter should lead to minimal but adequate facilities and minimize the impact on operational procedures and costs. To achieve these objectives, earlier and more complete interaction and collaboration between the facility designers, SSAC, and the IAEA is recommended.[1]

SBD Processes

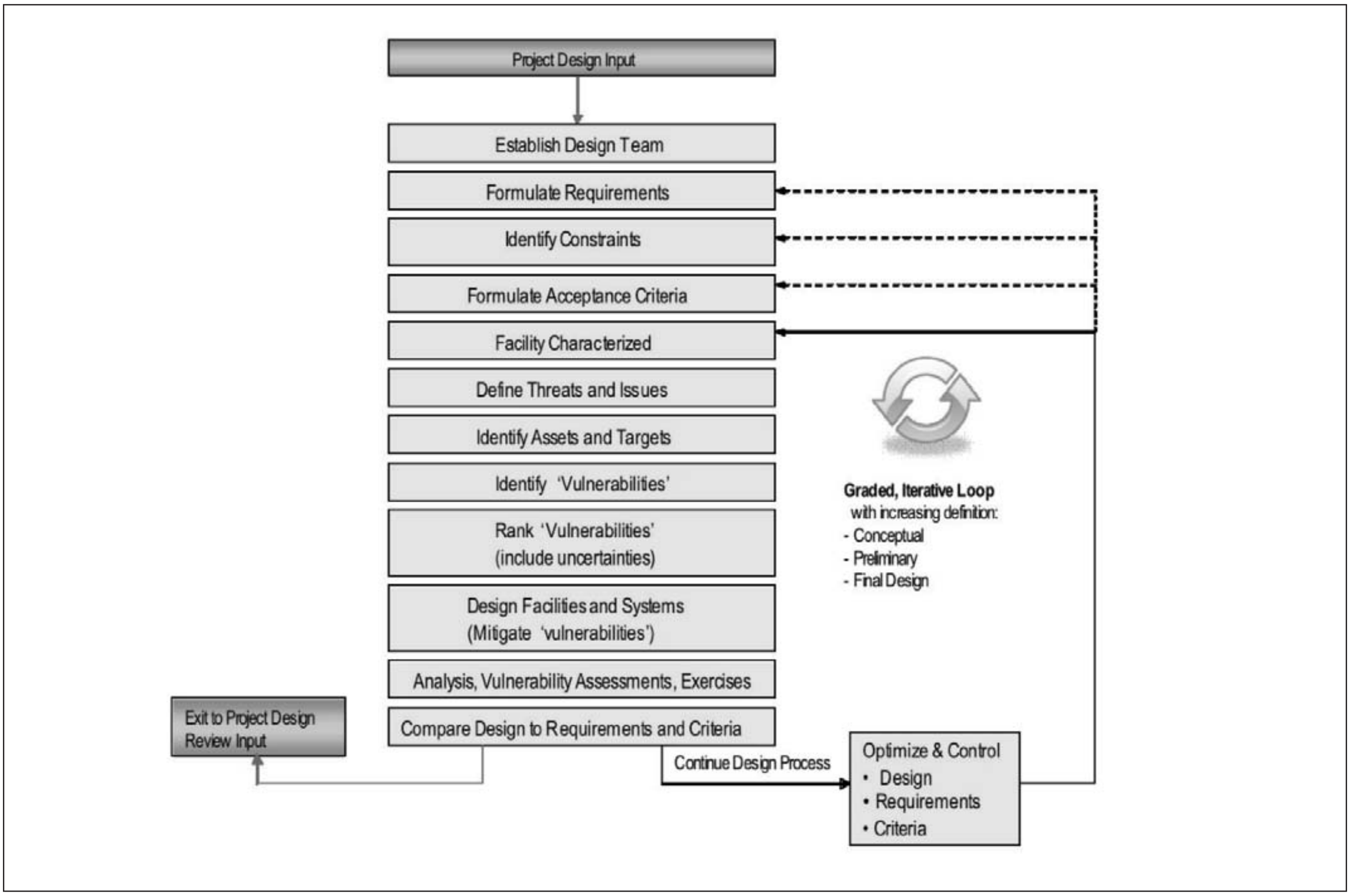
Example of the SBD Process within a National Regulatory Environment

Design processes for SBD form the second technical pillar of the ISBD framework, see Figure 2. SBD is a process that must be integrated with the project management, engineering design (especially including safety) and systems engineering process utilized for the design and construction of nuclear facilities.[5,6] To initiate studies, the development of a proposed SBD process within a particular regulatory system was needed as an exemplar of a state environment. The use of the DOE regulatory environment was selected as the example study presented here due to existing knowledge, experience and the completeness, detail and availability of the directive system. The study generated a single proposed SBD process including identification and description of activities, deliverables, interfaces, and hold points covering both domestic regulatory requirements and international safeguards.

The conventional main phases of design, i.e., conceptual, preliminary, and final, are shown in Figure 3, and comprise cycles of safeguards activities which contain: design iteration (SBD design loop, see Figure 4), review, risk/opportunity assessment, vulnerability assessment, cyber security plan, specification development, effectiveness review, strategy development, and stakeholder response. Within each phase, the SBD process calls for the SBD team to receive design information from the overall facility project design, and perform a loop of specialized safeguards and security related design activities, see Figure 4. These cover safeguards requirements definition, safeguards design, assessment of design effectiveness (or conversely vulnerability), reiteration of design if needed, and exit to project design review when appropriate with subsequent repetition if needed. Collaboration with specialist design teams, such as safety, is required. The loop is graded in that design definition increases in each design phase whilst the overall pattern is repeated for comment resolution as necessary. There are iterations of the SBD design loop initially in the three main design phases, and lastly during facility construction, transition, startup, and closeout.

The proposed SBD process, for the example environment, develops an overall safeguards design strategy, which documents the design approaches that the project proposes to meet the domestic safeguards requirements from directives and performance requirements from vulnerability assessment, cyber-security planning, MC&A process analysis, and proliferation barrier analysis. The latter two are projected new analyses to support the early identification of the design features relied on to meet safe-

Figure 4. SBD design loop



guards performance requirements. The MC&A process analysis identifies the design features and associated system performance requirements needed to meet the established nuclear MC&A standards, commensurate with the maturity of the design. This analysis is tailored to the complexity of the facility and the safeguards significance of the nuclear material housed at the facility. The second proposed analysis is the proliferation barrier/safeguardability analysis, discussed later in this paper, which identifies the design features and associated performance requirements needed to meet intrinsic and extrinsic proliferation risk reduction requirements.

The study was performed in two convenient but otherwise arbitrary stages: firstly, developing a process driven only by the combination of domestic requirements and SBD performance requirements and, secondly, modifying the first results to integrate the additional effects of incorporating international (IAEA) requirements. The study generated a proposed SBD process comprising fifty-five process steps, which included fourteen to account for the IAEA safeguards requirements (notably design information questionnaire, facility safeguards approach, facility attachment, and design information verification) and forty-one in support of domestic requirements.[4] The SBD methodology adopted and the level of detail is comparable to that for integration of safety into the design process.[10] The step-wise approach was to simplify the study and facilitate its visual representation by means of two series of flowcharts.[4] Although new directives have not been drafted for use of SBD within the acquisition system, the SBD process is considered to be sufficiently developed to merit broader stakeholder review and be tested on a pilot scale for an actual project. These exercises would evaluate and improve process viability and help determine the best way to effect institutionalization within the regulatory structure.

Key Features of the SBD Process

Following the study of integrating the SBD process with that for design and construction management, the SBD project team extracted fundamentals.[11] The principal features were determined to be:

- Early involvement of SBD team in the design effort
- Early identification of safeguards, MC&A, and physical protection requirements
- Early formulation of intrinsic features that will benefit the design
- Closer integration of safeguards, MC&A, and security with

project design leading to improved risk management, cost estimates and schedules
- A clear and simple interaction plan between safeguards and the facility design process which identifies required activities and timeline and provides detail and analyses in each phase of design
- Specific requirements for owner/stakeholder approval of design approaches and associated risks at key decision points
- Sufficient flexibility to incorporate all regulatory requirements into the design of nuclear facilities

In general, there is unlikely to be a unique "best way" to integrate design requirements and assessment methodologies, so that flexibility and judgment in application of the SBD process is important. Some further work in this area may examine a minimal set of baseline safeguards performance requirements, as seen within the physical protection, MC&A, and international safeguard requirements of a range of states. Within this basic requirement set, the minimal process steps for SBD and their optimal phasing could be established. These SBD activities may then be integrated more easily within a general project management sequence that might incorporate a variable number of hold points and could form a single path or comprise multiple parallel paths. This may bring increased flexibility to institutionalize SBD within the framework of any oversight regime.

Supporting Technology and Methodology

Overview

Technology and methodology form the third technical pillar of the ISBD framework, see Figure 2. This area includes development of technologies, including instrumentation and data processing, for better supporting safeguards approaches,[12] and methodological toolkits for assessing facility designs for compliance with design requirements.[13] Other technological applications are the development of engineering standards and guidelines, some widely applicable to nuclear facilities and others to specific facility type, and the study of best practices and lessons learned for relevant nuclear facilities. The pursuit of improved precision and accuracy of measurement of material mass and isotopic content in various geometries, chemical and radiochemical environments, and phase dispersions is longstanding. Some assessment methodologies are under development and not yet well accepted by regulators and industry. Vulnerability assessment in relation to physical security is relatively well developed on a deterministic, prescriptive basis. Assessment of proliferation risk reduction, including safeguardability, is less well developed. As was experienced in the field of safety including the present trend toward probabilistic safety analysis, there is an expectation that full maturity will take significant time as implementing authorities and technical experts gain experience. The SBD process has the flexibility to enable parallel process testing and methodology development. The emphasis in this section is on the status of developments in proliferation resistance and the sub-topic of safeguardability.

Safeguards Objectives

The goal of international safeguards for nuclear facilities is to provide timely detection of the diversion or misuse of the facility to acquire materials for nuclear explosives. The safeguards system is subject to two distinctly different types of potential errors: Type I errors (false alarms/false positives), and Type II errors (non-detection of diversion or misuse). The plant operator, the state, and the IAEA all have a mutual interest in designing and operating facilities to achieve a low rate of false alarms (anomalies requiring an IAEA investigation) and a very low rate of false positives (where an IAEA investigation cannot confirm the absence of diversion or misuse, or incorrectly concludes that diversion or misuse has occurred).

The risk of false alarms and false positives will be dominated by safeguards failures that can occur due to off-normal, accident, and physical security events. The systematic identification of potential events and their potential frequencies is a central part of the design of the safety and physical security systems for nuclear facilities. Thus substantial benefits can come from closely integrating the design of the international safeguards system with the safety and physical security system design processes. Clearly, safeguards, safety, security, and reliability (process control) all benefit from an accurate and timely knowledge of the location of nuclear materials.

On the other hand, Type II non-detection errors do not result from random initiating events, but instead from the strategic decision of a state to divert material or misuse a facility. This distinction is important, because the state can be deterred from attempting diversion, even when the probability of non-detection errors is relatively large (say up to 10 percent), without generating much risk that diversion will be attempted. While in principle, a state could divert material ten times in order to obtain a reasonable probability of having one diversion go undetected, this is not a strategically rational behavior.

It is also important to note that the state, as a strategic actor, has the capability to alter the frequency of some types of initiating events to be larger than the normal rate, just as in the case of physical protection where the normal, random probability of different combinations of equipment or system failures can be changed by the strategic actions of an adversary.

Under SBD, the interlinkages between international safeguards, safety, and reliability are considered explicitly. This does provide the opportunity to design safeguards systems specifically to achieve very low rates of Type I errors, which benefits safety and reliability as well.

Proliferation Resistance Measures

Proliferation resistance is defined by the IAEA as "that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material or misuse of technology by the state seeking to acquire nuclear weapons or other nuclear explosive devices."[14] The term "proliferation resistance" relates to the host state as the threat, and greater technical capability is ascribed to the host state in carrying out a proliferant act than to a non-state adversary. It is essential to understand that no nuclear energy system can be proliferation proof, but different systems can present varying degrees of proliferation risk that can be reduced by the combined actions of the proliferation barriers acting in that system, which make diversion or misuse technically more difficult to carry out and more readily detectable. Institutions and states can erect and maintain institutional barriers to proliferation and examples of such extrinsic measures include treaties, commercial and legal arrangements, and export controls.

Designers can contribute to proliferation risk reduction through the selection of processes and incorporation of facility design characteristics, i.e., intrinsic features, which either directly impede proliferation pathways or facilitate the cost effective application of other extrinsic measures, like the activities associated with international safeguards. Intrinsic features include inherent physical properties of the system and are in general robust and desirable because they are very difficult to modify or overcome.[7] A nuclear energy system's proliferation resistance may vary according to the specific host state threat and results from the combined effect of all its different barriers. It results from the application of international safeguards plus other proliferation barriers. The incorporation of the latter in facility and process design can be readily implemented through the proposed SBD process. Ultimately the specification of relevant requirements will be necessary since project management systems do not allow designers to act in their absence although the vendor may follow a level of custom and practice. Future efforts should be directed at defining realistic requirements and establishing the methods by which system performance against these requirements can be assessed.

The proliferation resistance and physical protection working group of the Generation IV International Forum (GIF) proposed six high-level measures for proliferation resistance, which are useful already and continue to evolve.[7] The evaluation for proliferation resistance then involves a systematic search for potential proliferation pathways, evaluation of measures for these pathways, comparison of pathways, and iterative improvement of the system design to reduce the attractiveness of potential proliferation pathways. The measures are:

- Detection Probability—The cumulative probability of detecting a proliferation segment or pathway.
- Detection Resource Efficiency—The efficiency in the use of staffing, equipment, and funding to apply international safeguards to the nuclear energy system.
- Proliferation Technical Difficulty—The inherent difficulty, arising from the need for technical sophistication and materials handling capabilities, required to overcome the multiple barriers to proliferation.
- Proliferation Cost—The economic and staffing investment required to overcome the multiple technical barriers to proliferation including the use of existing or new facilities.
- Proliferation Time—The minimum time required to overcome the multiple barriers to proliferation (i.e., the total time required for the project by the host state).
- Fissile Material Type—A categorization of material based on the degree to which its characteristics affect its utility for use in nuclear explosives.

The first two measures relate specifically to the application of international safeguards to the nuclear energy system. The term safeguardability is used in the context of future nuclear energy systems and is defined as "the ease with which the system can be effectively and efficiently placed under international safeguards."[7] These safeguards related measures suggest the importance of designing facilities to make it easier to apply safeguards that are efficient and provide high detection probability for all potential proliferation pathways. Three further proposed measures describe other barriers presented by the system to the proliferator and suggest the design objective of making it technically difficult, time-consuming, and costly for the potential proliferator to exploit the nuclear energy system. The sixth measure, relating to the attractiveness of the material obtained from a proliferation pathway, is essentially established by the fuel cycle properties. It is important that all nuclear materials, which can be used in a nuclear explosive device, be subject to high standards for safeguards and security, and recently reported research indicates that a number of nuclear materials and grouped products are attractive for use in nuclear explosives.[15]

Proliferation Resistance Assessment

The development of a mix of methodological approaches was initially proposed to define and assess the performance of nuclear energy systems of the future.[14] Progress has been made with a three-pronged methodological approach to assessment of proliferation resistance and physical protection; viz. checklist, qualitative, and quantitative approaches. The IAEA-led International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) program has developed the checklist approach,[8] while GIF has pursued development of a risk-informed methodology for both the qualitative and quantitative assessment approaches.[7]

The checklist approach considers specific system design characteristics or properties, one at a time. The GIF working group evaluation methodology on the other hand calls for a holistic, risk-informed analysis that examines the relative performance of whole nuclear energy systems. The two methodologies are useful today, are proving to be complementary in their use, and both continue to evolve.[13] The risk-informed analysis approach is particularly valuable as a tool for systematically identifying vulnerabilities of a system and in guiding the use of resources for their mitigation, whilst checklists provide increased assurance of completeness in analysis. For these reasons, a risk-informed, holistic analysis approach coupled with a systematic review of previous experience, like that advocated by the GIF working group, is particularly well suited for application in the SBD process.

Risk-informed analysis commonly uses the construction of event trees (or equivalent) to describe the possible strategies (pathways) that an adversary might exploit in order to achieve the desired objectives. For preliminary work, the process of constructing and inspecting the trees in a disciplined fashion, combined with expert judgment, is a practicable approach to identifying and estimating vulnerabilities and then allocating resources to mitigate them. This type of analysis is valuable during the conceptual design phase. As design detail increases the definition of the events considered changes accordingly. As design progresses, more rigorous, quantitative analysis of performance of the system as a whole takes place including assessment of uncertainties. This graded, iterative approach to SBD as proposed here is illustrated in Figure 4. It is not yet clear what extent of application of such methodology will prove to be economically justified.

GIF has continued to develop its methodology with the aid of a series of studies. The example sodium fast reactor (ESFR) consists of four sodium-cooled fast reactors of medium size co-located with an on-site dry fuel storage facility and a pyrochemical spent fuel reprocessing facility. The objectives of the case study were to exercise the GIF proliferation resistance and physical protection methodology for a complete Gen-IV reactor/fuel cycle system; to demonstrate, via the comparison of different design options, that the methodology can generate meaningful results for designers and decision makers; to provide examples of evaluations for future users; and to facilitate other ongoing collaborative efforts (e.g., INPRO) and other national efforts.[16,17] Consistent with the foregoing, it was found that structured qualitative analysis can produce traceable, accountable, and dependable results providing useful information to system designers, and when applied at the conceptual design level can aid in the development of functional requirements for SSC, which can guide subsequent detailed design.

Benefits and Challenges

SBD has the potential to improve control of cost and schedule risk during facility design and construction and reduce life-cycle cost associated with facility design, construction, and operation. There is a wide range of technologies and facility types used within the nuclear fuel cycle including defense facilities. These have differing safeguards, safety and security aspects, which span emphasis on stability of operation to security of material held. The basic SBD approach is expected to be applicable, with adaptation, to all nuclear facilities regardless of the state regulations or directives governing their design, construction, and operation. Although national regulatory environments differ, the same basic decisions need to be made and the same basic management processes are required. SBD brings focus to state needs to include international safeguards aspects within facility acquisition and design, and also enables IAEA to bring attention to its requirements to conduct international safeguards including verification activities in an economical, reliable manner for the facility owner/operator. Particularly through focus on intrinsic safeguards features, SBD is supportive of recent U.S. NRC policy for advanced nuclear energy systems that requires concurrent consideration of safety and security requirements, while designing a facility, resulting in an overall security system that requires fewer human actions.[18] SBD has the potential to provide the greatest benefit for innovative designs, i.e., designs for facilities with new processes and/or new product and waste streams, where technological experience on which to base the selection of major options, such as process flow-sheet, equipment selection, and facility layout, is limited.

The authors believe an SBD process can be usefully applied today, within a nuclear facility design process, with tangible benefits for most projects by tailoring the process to the applicable regulatory environment. However, use of the proposed SBD process may need the introduction of formal requirements, e.g., regulations, or industry initiatives based on firm evidence of value, such as pilot testing or demonstrations. These do not yet exist given the early stage of development. Tests or other activities, that illustrate the benefits of applying the SBD process, could be of particular value. Other challenges remain. The SBD process relies on the incorporation of international safeguards, MC&A, security, and safety requirements stemming from existing treaty commitments, laws, regulations, stakeholder interests, industry standards, political will of a state for transparency, etc. Where safeguards related guidelines or requirements are incomplete, or difficult to translate into meaningful design requirements, they must be improved or replaced. There are no broadly agreed design standards or formal design requirements for proliferation risk reduction beyond those for international safeguards. Other barriers to the successful deployment of the SBD process include the lack of a comprehensive safeguards culture, use of differing terminologies, intellectual property concerns, the sensitive nature of safeguards and security information, differing nationality and clearance of international architect-engineer staff, and the potentially divergent or conflicting roles and interests of participating organizations in the process. Efforts to institutionalize SBD must address these major issues.

Conclusions

- The authors believe that the development and application of a Safeguards-by-Design (SBD) process for new nuclear facilities has promise to reduce nuclear security and proliferation risks, and enhance safety in an economical way, while raising operational efficiency. Done properly, SBD has excellent potential to benefit all stakeholders, including specifically the IAEA and the owner/operator.

- International work, under the auspices of an IAEA workshop, explored SBD for international safeguards and sought a more collaborative approach that integrates these into the facility design process earlier than is presently done. The aim is to develop effective safeguards that save operating costs for both the agency and facility operator.
- The application of the SBD approach to meeting national requirements for nuclear material control and accountancy, physical security and safety will directly contribute to the success of the SBD process for international safeguards, and may even prove to be a prerequisite.
- The proposed SBD process is considered to be adaptable to the needs of any state nuclear organizational structures, complementary to the proposed SBD process within the international safeguards environment coordinated by IAEA and supportive to the IAEA integrated 3S concept.
- Components of SBD include requirements definition, design processes, and supporting technology and methodology. These improve the effectiveness and efficiency of the safeguards design process as part of nuclear facility design, construction, and operation.
- The proposed SBD process is expected to be readily adaptable to almost all regulatory, project management, and engineering environments and is applicable to a wide range of nuclear facilities; although much work remains to achieve international consensus and adoption.
- The center of attention of the proposed SBD process is the early inclusion of requirements, and the early identification of beneficial, e.g., intrinsic, design features. Current engineering approaches emphasize front end design since the possibility to significantly influence major design features, such as plant layout, SSC, and processes, largely finishes with the conceptual design phase.
- The proposed SBD process can be applied beneficially today, using existing requirements and methodologies. The results obtained are likely to be improved as more of the SBD framework is used and the designer's methodological toolkit is expanded and matured. The IAEA workshop participants[1] and the authors view the development of design principles, guidelines, and best practices as a valuable near term addition.
- Key features of the proposed SBD process include: initiation of safeguards design activities in the pre-conceptual planning phase, early appointment of an SBD team, timely definition of requirements, participation in facility design options analysis in the conceptual design phase to enhance intrinsic features, definition of new deliverables akin to safety reports, assisting the project director in ensuring safeguards requirements are met, and formal communication of risks and management strategies to decrease the cost and schedule uncertainties.
- The benefits of SBD should be recognized within the broader proliferation resistance context. This is because a gauge for how much proliferation risk reduction is being achieved in an SBD activity is needed to be able understand its relative value with regard to economic, operational, safety, and security factors. Furthermore, there is a need for continuing development of assessment methodologies for proliferation resistance and physical security of nuclear facilities. These methodologies are useful in design development, and for determining whether systems meet design objectives or requirements and can demonstrate proliferation risk reduction.

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Moving Toward Multilateral Mechanisms for the Fuel Cycle

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Abstract

Multilateral mechanisms for the fuel cycle are seen as a potentially important way to create an industrial infrastructure that will support a nuclear renaissance and at the same time not contribute to the risk of nuclear proliferation. In this way, international nuclear fuel cycle centers for enrichment can help to assure a supply of nuclear fuel that will reduce the likelihood that individual states will pursue this sensitive technology, which can be used to produce nuclear material directly usable in nuclear weapons. Multinational participation in such mechanisms can also potentially promote transparency, build confidence, and make the implementation of International Atomic Energy Agency (IAEA) safeguards more effective or more efficient. At the same time, it is important to ensure that there is no dissemination of sensitive technology.

The Russian Federation has taken a lead role in this area by establishing an International Uranium Enrichment center (IUEC) for the provision of enrichment services at its uranium enrichment plant located at the Angarsk Electrolysis Chemical Complex (AECC). This paper describes how the IUEC is organized, who its members are, and the steps it has taken both to provide an assured supply of nuclear fuel and to ensure protection of sensitive technology. It also describes the relationship between the IUEC and the IAEA and steps that remain to be taken to enhance its assurance of supply.

Using the IUEC as a starting point for discussion, the paper also explores more generally the ways in which features of such fuel cycle centers with multinational participation can have an impact on safeguards arrangements, transparency, and confidence-building. Issues include possible IAEA safeguards arrangements or other links to the IAEA that might be established at such fuel cycle centers, impact of location in a nuclear weapon state, and the transition by the IAEA to state-level safeguards approaches.

Background

There is widespread support for a future in which the use of nuclear energy is a growing component of the world's energy production, but in which, at the same time, the spread of sensitive nuclear technologies—and thus the risk of proliferation—is minimized. A key element of achieving these objectives is the development of mechanisms to provide nuclear fuel to customers at competitive prices and an assurance of supply so robust that they have no economic or energy security incentives to pursue indigenous enrichment or reprocessing programs. Multilateral approaches to the nuclear fuel cycle are an important means to create such a mechanism.

Such multilateral approaches have already received considerable review and attention. For example, in 2004 the International Atomic Energy Agency (IAEA) Director General appointed an international group of experts to consider their potential.[1] At the Eurasian Economic Community summit in January 2006, the president of the Russian Federation, V.V. Putin, made a statement[2] on the peaceful use of atomic energy in which he noted the need for the establishment of a global nuclear power infrastructure, ensuring equal access to nuclear power for all interested parties and, at the same time, reliable compliance with the requirements of the nonproliferation regime. A key element of such an infrastructure, he said, should be the creation of a system of international centres providing nuclear fuel cycle services, including enrichment, under the control of the IAEA. The main assurance that the initiative should provide is that a country complying with its nonproliferation commitments must be sure that, whatever the turn of events, whatever changes take place in the international situation, it will receive the services guaranteed to it.

More recently, U.S. President Barack Obama, while he was a candidate, issued a fact sheet[3] that addressed the issue of fuel assurances as follows:

> Prevent Nuclear Fuel from Becoming Nuclear Bombs: Barack Obama will work with other interested governments to establish a new international nuclear energy architecture—including an international nuclear fuel bank, international nuclear fuel cycle centers, and reliable fuel supply assurances—to meet growing demands for nuclear power without contributing to the proliferation of nuclear materials and fuel production facilities.

The Russian Federation has taken a lead role in establishing an international nuclear fuel cycle center for the provision of enrichment services. In particular, it has created an international uranium enrichment center (IUEC) at its enrichment plant at the Angarsk Electrolysis Chemical Complex (AECC). In a communication to the IAEA Director General in June, 2007,[4] the Russian Federation highlighted important aspects of international nuclear fuel cycle centers and the IUEC, including;

- Nondiscrimination within the Nonproliferation Treaty (NPT): A global nuclear power infrastructure to ensure equal access to nuclear power and, at the same time, reliable compliance with the requirements of the nonproliferation regime
- IAEA participation: A system of international centers providing nuclear fuel cycle services, including enrichment, under the control of the IAEA
- Assurance of supply: A guarantee that a country complying with its nonproliferation commitments will receive the services guaranteed to it regardless of events or whatever changes take place in the international situation
- Protection of technology: No transfer to IUEC participants of uranium enrichment technology or information that constitutes a state secret
- Safeguards: Making the IUEC eligible for safeguards under Russia's voluntary offer safeguards agreement
- Uranium reserve: Setting aside a specific quantity of enriched uranium product as a deposit for a guaranteed stockpile at the IUEC in a quantity of up to one to two full reactor loads; and a regulatory basis such that the shipment of material out of the country at the request of the agency is guaranteed
- Advisory body: Establishment of a joint advisory committee with the presumption that the IAEA will be represented in the committee

All in all, the IUEC contains elements that many observers have considered important for multilateral nuclear arrangements: accessibility, assurance of supply when there is compliance with nonproliferation commitments, IAEA safeguards, and a uranium reserve to provide a physical "fuel bank" to underscore the assurance of supply.

Status of the IUEC

The Russian Initiative to Establish an International Centers Network Under IAEA Control

In accordance with the statement of President Putin noted above, the objectives of the Initiative are to:

- prevent an uncontrolled proliferation of sensitive nuclear technologies that could be used not only for civil but also for military purposes;
- increase the role of nuclear energy in provision of global energy assurance;
- develop the global nuclear energy infrastructure via the establishment of an international nuclear fuel cycle centers network; and
- provide non-discriminatory and assured access to products and services of the nuclear fuel cycle for those states that are currently developing nuclear power.

While the Russian president's initiative suggested that four types of centers could be created—uranium enrichment, reprocessing of spent fuel, training of personnel for the nuclear industry, and development of innovative atomic energy technologies—it was decided to first launch a pilot project to establish the International Uranium Enrichment Centre (IUEC) on the site of the Angarsk Electrolysis Chemical Complex (hereinafter the AECC) taking into account the developed infrastructure there. This was announced in September 2006 by Rosatom at the 50th session of the IAEA General Conference.

The IUEC was established in partnership with the Republic of Kazakhstan as a joint-stock company. This structure ensures the IUEC's financial independence from the state budgets of the participants. The main function of the IUEC is to provide its participating companies with guaranteed access to uranium enrichment capabilities. At the same time, the Russian side will not transfer to IUEC participants the sensitive uranium enrichment technology or classified information that constitutes a state secret.

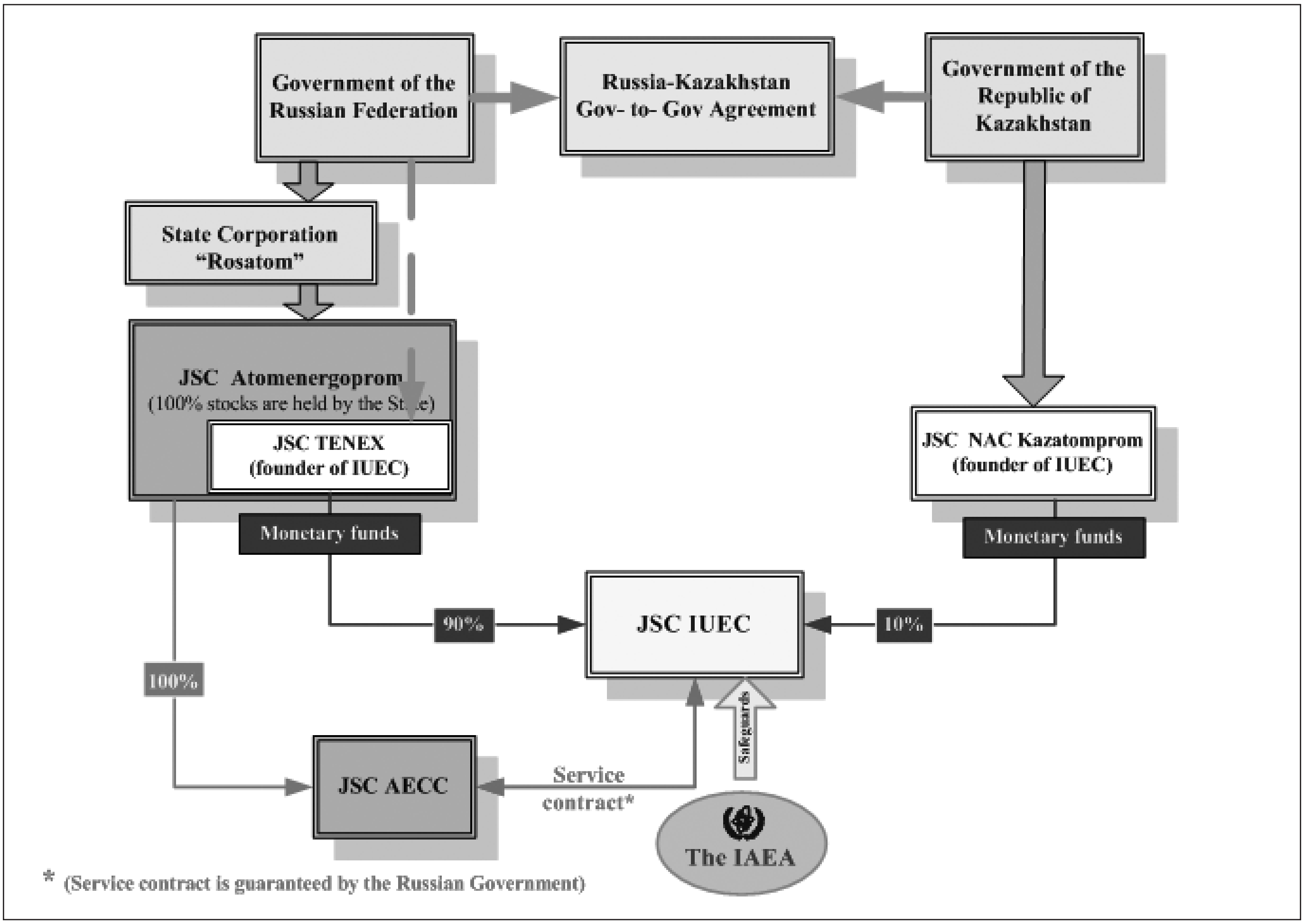
In addition, on December 27, 2007, the government of the Russian Federation took the decision to include the IUEC on the list of Russian facilities that could be subject to the IAEA Safeguards in the framework of the Safeguards Agreement between Russian Federation and the IAEA - INFCIRC/327. The Russian government decided that in case of IAEA safeguards application to IUEC nuclear material, the costs of safeguards would be covered by the Russian Federation. As of early 2009, arrangements to put IUEC nuclear material under IAEA safeguards were under negotiation.

Intergovernmental Agreement

The agreement between the governments of the Russian Federation and the Republic of Kazakhstan about the establishment of the IUEC sets forth the fundamental basis for its goal, structure, and governance, including:

- Main goals and terms for the IUEC operations;
- Executive bodies and authorized companies;
- Form of incorporation and location of the IUEC;
- Basic requirements to member-countries (in full compliance with their NPT obligations), whose nominated companies would become shareholders of the IUEC;
- Provision that there be no access by foreign shareholders to the Russian uranium enrichment technology and classified information;
- Application of IAEA safeguards to IUEC nuclear materials;
- IAEA participation in the work of IUEC's Joint Consultative Commission established for the effective implementation of

Figure 1.



the objectives of the agreement. As may be agreed with the IAEA, the representative from the IAEA may participate in the work of the commission being entitled to the consultative capacity.

The Structure of the IUEC

The structure of the foundation of the IUEC is shown in Figure 1.

The initial Intergovernmental Agreement between Russia and Kazakhstan entered into force in August 2007. It nominated JSC TENEX and JSC NAC Kazatomprom as founders of the IUEC. It was then also established in August 2007 in the form of a joint-stock company (JSC). The initial share distribution was: JSC TENEX–90 percent and JSC NAC Kazatomprom – 10 percent. The IUEC then concluded service contracts with the AECC.

The IUEC Basic Principles

Article 3 of the agreement between the Russian Federation and the Republic of Kazakhstan establishes the main task of the IUEC as securing assured access to the uranium enrichment capacities of the AECC for organizations—participants of the center from countries that do not develop their own uranium enrichment capacities.

The IUEC basic principles are:

- Non-discrimination, i.e., equal membership terms for all states concerned;
- Assured access of the IUEC member-states to enriched uranium product (EUP) and/or SWU;
- The IUEC operation is based on the existing market relations;
- Transparency of the IUEC operation through the application of IAEA safeguards to nuclear material under the ownership of the center;
- No access of foreign members to the Russian uranium enrichment technology and classified information;
- Advantages of IUEC to its member-countries through guaranteed access to goods and services (EUP/SWU) will exceed any benefits that might be obtained by developing and relying on their own sensitive nuclear fuel cycle facilities.

Background of the IUEC foundation

Subsequently membership in the IUEC has grown. In November 2007, the Republic of Armenia nominated the JSC Armenian NPP to join. On June 24, 2008, the Republic of Ukraine declined to nominate the concern Nuclear Fuel of Ukraine to join the IUEC.

Maintenance of a Guaranteed Physical Reserve as a Second Direction of the IUEC Activity

In response to the IAEA Director General's initiatives on multilateral approaches to the nuclear fuel cycle and on assurance of fuel supply mechanisms, the government of the Russian Federation has proposed to establish a guaranteed physical reserve of 120 metric tons of LEU. This will be in the form of UF_6 with an enrichment level ranging from 2.0 percent to 4.95 percent and will be stored at the IUEC under agency safeguards for the use of IAEA nember states experiencing a disruption of LEU supply. The costs of safeguards will be covered by Russia.

This LEU reserve would constitute a practical application of the provisions of Article IX of the Statute of the IAEA on the supply of nuclear material. The LEU reserve at the IUEC would be intended to serve as a guaranteed supply to supplement the existing commercial market in nuclear fuel and as a protection of interested member states against possible disruptions of LEU supplies.

For a consumer state to receive nuclear material from this reserve, the IAEA would have to draw a conclusion that all nuclear material had been accounted for; that there was no indication of diversion of declared nuclear material; and that there would not be any safeguards implementation issues concerning the state under consideration by the IAEA Board of Governors. The LEU would be made available to any non-nuclear-weapon state member of the IAEA that has an effective safeguards agreement with the IAEA requiring the application of safeguards on all of its peaceful nuclear activities.

Important features of the LEU Reserve at the IUEC include:[5]

- **Non-discriminatory and inclusive nature**—it would be available to all IAEA member states meeting the above-mentioned attributes;
- **Non-restrictive**—there would be no requirement for interested IAEA member states, explicit or implicit, to forgo any rights, including rights to develop a country's national fuel cycle capabilities;
- **No cost to the IAEA**—there would be no financial burden on the IAEA or its member states, since all start-up, storage, maintenance, safeguards, and other costs would be covered by Russia; the cost of any LEU supplied from the reserve would be covered by the consumer state at the time of delivery;
- **Non-exclusive**—it would not conflict with or hinder the establishment or operation of any other elements of assurance of supply mechanisms;
- **Non-disruptive**—the LEU reserve would not undermine the commercial nuclear fuel market; the quantity of LEU delivered would be relatively small compared to the overall market volume, and the actual market spot price would be charged to the consumer state;
- **No delays**—the government of the Russian Federation in its agreement with the IAEA on establishing an LEU physical reserve would confirm that all necessary authorizations and export licenses would be issued and that the LEU could be exported without undue delay for supply to a consumer state;
- **Pro-cooperative**—it would work in synergy and harmony with various initiatives on nuclear fuel supply assurances, current and future, and contribute to a menu of other fuel assurance options that may be agreed upon by IAEA member states, such as for example the IAEA LEU bank proposed by the Nuclear Threat Initiative, as well as the multilateral enrichment sanctuary project (MESP) proposed by Germany;
- **Prolonged**—it would be established for an indefinite period and replenishment of the supply of LEU is envisaged;
- **Promotional**—it would facilitate the continuing and future use of nuclear energy for electricity production, and support its beneficial expansion to help meet increasing global energy needs.

A flow chart of establishment and utilization of a reserve of LEU for the supply of LEU to the IAEA for its member states is shown in Figure 2.

Membership of the IUEC

At the fifty-second session of the IAEA General Conference held in Vienna in September 2008, Sergey Kirienko in his statement[6] said that, "…membership of the Centre was open to other countries, without any political conditions…."

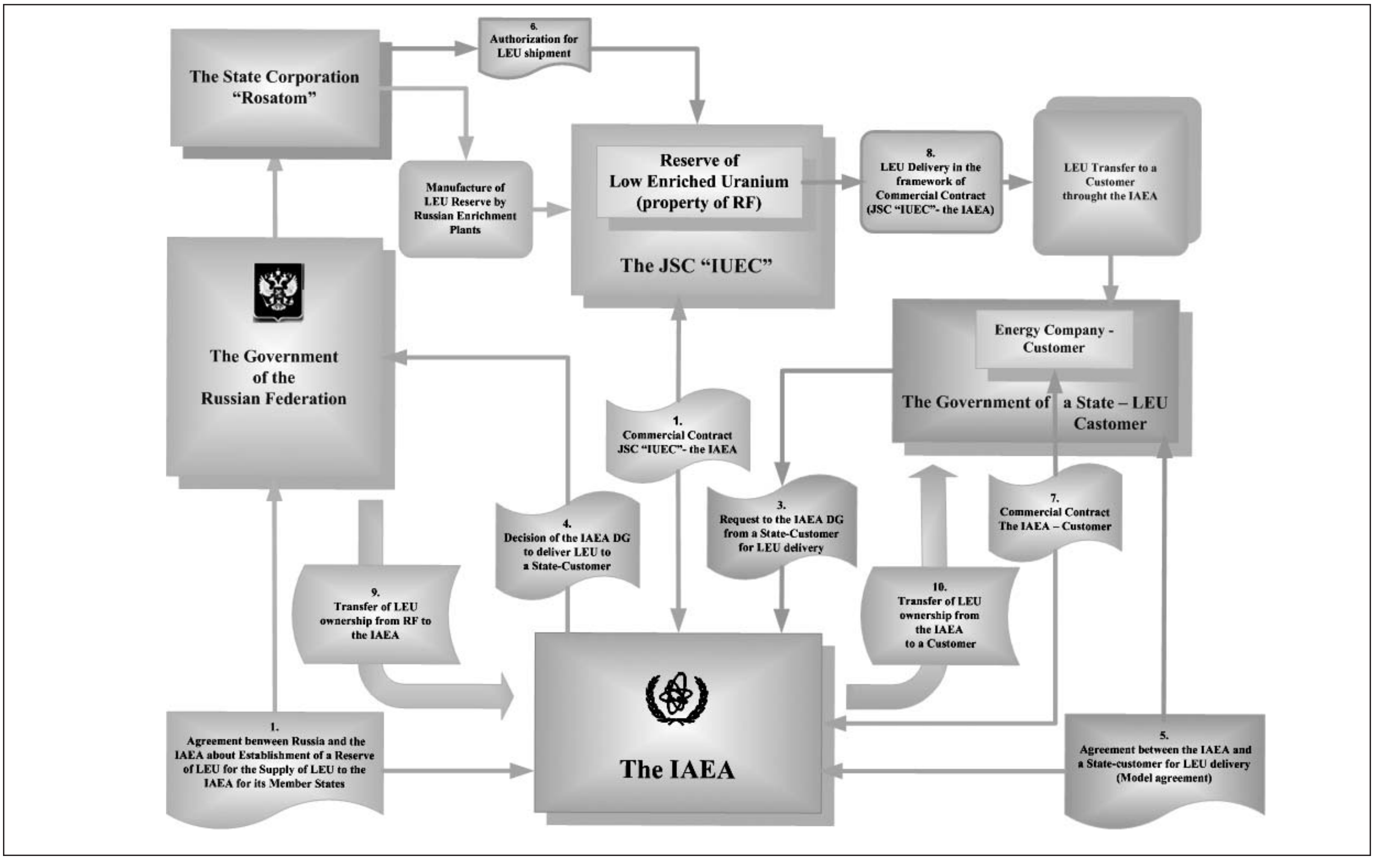
A complete structure of the IUEC is shown in Figure 3.

- Authorized companies of new member-countries can join the IUEC on the basis of separate government-to-government agreements.
- Article 5 of the agreement on foundation of the IUEC says:

  > "…Such participation is carried out based on separate government-to-government agreements between the Parties hereto and governments of the third states in the manner prescribed in the Articles of Association of the center…"

- As new members join, there is a redistribution of shares in the IUEC chartered capital that is obtained by reducing JSC TENEX share fraction as follows:
  - JSC TENEX
    50 percent +1 Share
  - JSC NAC Kazatomprom
    10 percent
  - New member-countries (all together)
    40 percent -1 Share

Figure 2.



The redistribution of shares in the IUEC chartered capital by reducing the JSC TENEX share fraction after the Republics of Armenia and Ukraine joined the IUEC is shown in Figure 4.

Multilateral Mechanisms

The IUEC should be seen as part of a growing trend to develop multilateral mechanisms to underpin growing interest by many states in beginning or expanding nuclear power programs. Such mechanisms can lend confidence to the market and create an improved nuclear nonproliferation environment.[7] However, the model adopted for the IUEC is not necessarily applicable in other circumstances. For example, the uranium feed purchased by the IUEC participants may not have associated with it the *label* or *flag* of another country or countries. Such flags generally carry with them requirements for retransfer that go beyond the requirements of full-scope safeguards and IAEA assurance of a positive safeguards status, as described above for the IUEC.

Further, each state or group of states desiring to create a multilateral mechanism will need to define for itself numerous features of it structure and operation, including for example: its business structure; ground rules for countries to participate; conditions of supply in routine circumstances and when a supply disruption is alleged; role(s) of IAEA other than safeguards; protection of sensitive technology; and means to promote transparency.

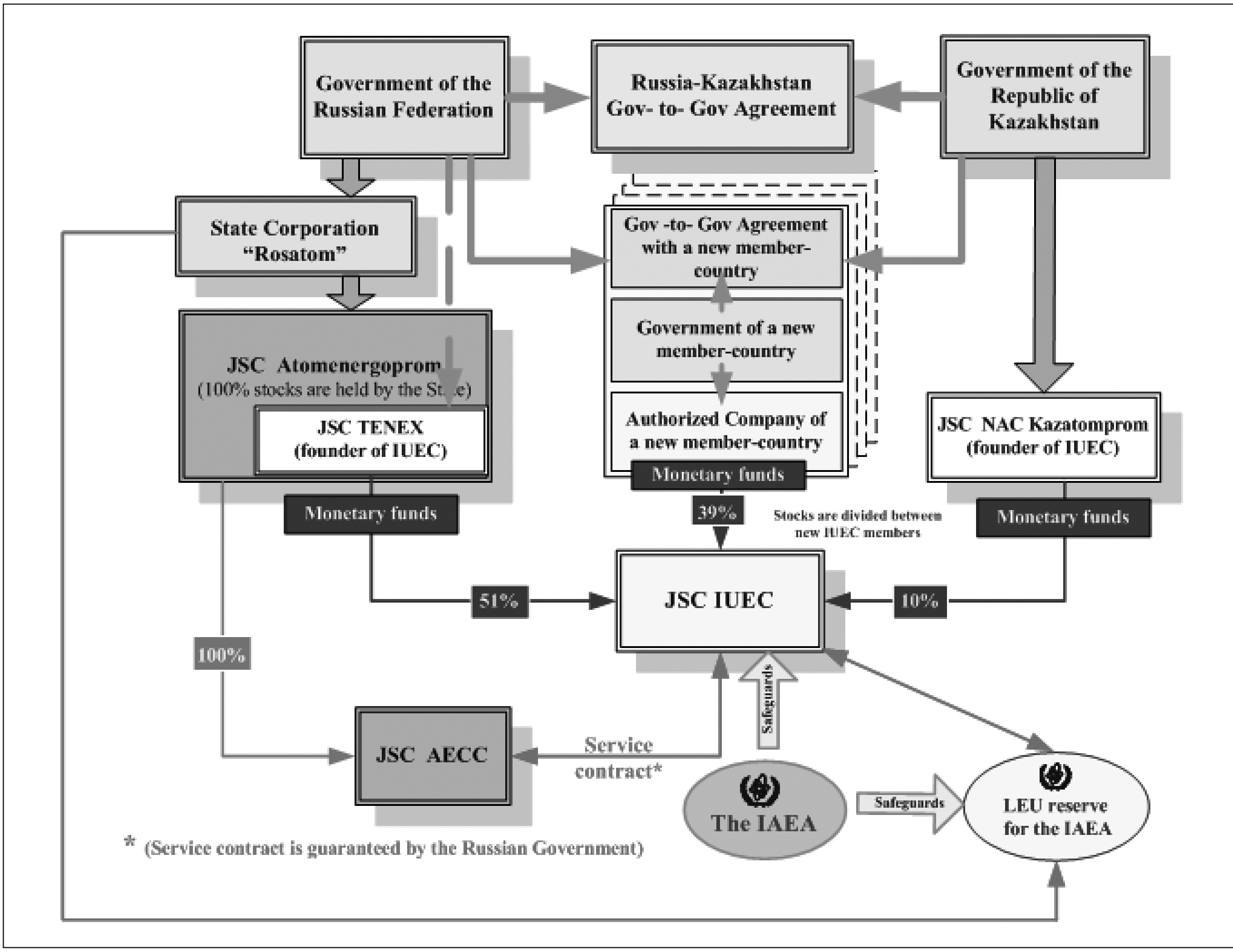
Nonetheless, using the IUEC as a starting point, it is worth exploring the ways in which features of nuclear fuel cycle centers with multinational participation can have an impact on transparency, confidence-building, and safeguards arrangements. Issues include possible IAEA safeguards arrangements or other links to the IAEA that might be established at such fuel cycle centers, impact of location in a nuclear weapon state, and the transition by the IAEA to state-level safeguards approaches.

Safeguards Arrangements

Many observers envision that the safeguards arrangements at multinational nuclear facilities would differ from those employed in a comparable national facility. For example, the expert group report cited above (INFCIRC/640) suggested that, “With respect to multinational nuclear arrangements (MNA), safeguards implementation by the IAEA should take into account the special positive nature of a multinational nuclear facility,” with the rationale that:

- “Participants, whether private or governmental, would be committed to transparency and openness through the continuous presence of a multinational staff; and
- Flows of materials would be mostly between partners to the MNA.

Figure 3.

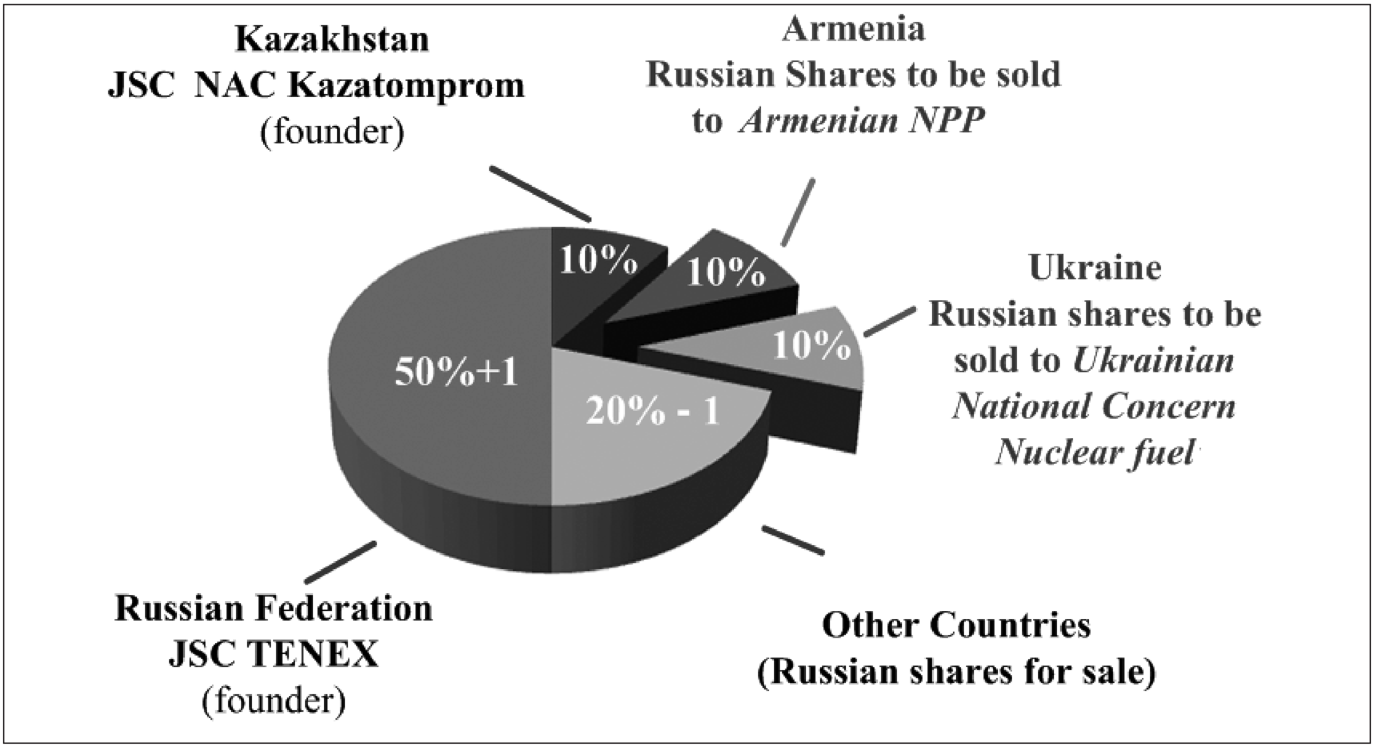


The experts suggested that, "This additional layer of international oversight would be recognized by the IAEA, possibly allowing thereby a reduction of the safeguards verification effort." Indeed, if the IAEA were to receive "through the continuous presence of a multinational staff" additional confidence that the operation of the facility had been normal and correctly and fully reported, it would be reasonable for the IAEA to take this into account, for example, by reducing the detection probabilities that it used for planning inspections.

The experts also cited the SAGSI May 2004 report that "noted that a large number of facilities receive nuclear materials from, and send nuclear materials to, other states, and also that many facilities employ multinational staff whose activities are interrelated with those of other states." They noted that, "SAGSI confirmed that the IAEA should give appropriate recognition to international interdependence under the so called 'state-level approach,' an approach that would include consideration of state specific factors such as the level of cooperation with the IAEA on safeguards implementation in the state, including consideration of openness and transparency; and the presence of a supportive and effective state System of Accounting for and Control (SSAC) of nuclear material." This context, the experts observed, is relevant for MNA joint facilities.

It would be for the IAEA to determine whether its confidence was enhanced by the nature of the MNA. At issue would be the extent of the information, its credibility, and how the IAEA would take it into account in modifying its safeguards approach. IAEA participation in an advisory board for the fuel cycle center, as is provided for in the IUEC, might benefit this process. Consideration might also be given to including IAEA inspectors in the "multinational staff" envisioned by the experts. Inspectors could play key roles in carrying out or supervising the plant's nuclear material accountancy system. Depending on the tasks that they performed, this direct participation in the operation of the

Figure 4.



plant might be the best way to enhance the confidence of the IAEA.[8] Such participation would, undoubtedly, raise legal issues that would have to be resolved. In addition, regardless of the staff, care would have to be taken to protect sensitive technology.

State-level Approach

The IAEA is transforming its safeguards system from a facility-by-facility approach to a state-level approach (SLA). In the latter, it views the state as a whole, takes into account all available information, and uses a careful and structured analysis of all aspects of an individual non-nuclear weapon states' (NNWS) nuclear activities and the nuclear weapon materials and technologies acquisition paths available to it that is embodied in the state evaluation report (SER). The SLA is based on the state-specific set of objectives that need to be addressed in order to determine the relative level and focus of safeguards activities needed for the IAEA to draw soundly-based safeguards conclusions. The SLA is used both to draw safeguards conclusions and to plan inspections.

Whether and how to take into account for these purposes the presence of a multinational facility in a given state is an open question. It may depend on whether the facility was in an "extra-territorial enclave," a possibility suggested in a proposal from Germany. In this case, it would not appear to have a direct bearing on the evaluation of the host state, although the willingness of the state to host the facility could be factored in.

In general, elements that are factored into a state-level evaluation include the quality of the SSAC; IAEA's ability to employ safeguards measures such as unattended and remote monitoring or short-notice random inspections (SNRI) and availability of information about the state's nuclear activities. As discussed above, the multinational facility should contribute to the overall transparency of the host state's nuclear activities.

SLA in a NWS

The fact that the IUEC is in a nuclear weapon state (NWS) provokes the general question of whether there is an applicable state-level approach for a NWS, recognizing that SLAs are intended to be applied to NNWS where both a comprehensive safeguards agreement and an Additional Protocol are in force. There they form the basis for drawing conclusions about the absence of diversion from declared nuclear material and of undeclared nuclear material and activities in the state as a whole.

On the other hand, when safeguards are applied in NWS, the safeguards conclusion is narrower—whether or not nuclear material has been removed from a facility other than in accordance with the terms of the relevant agreement. For obvious reasons, there is not, in these cases, any objective of detecting diversion to nuclear weapons.

The technical objective of safeguards is also different in NWS than in NNWS, in particular by being facility specific. Russia's voluntary offer safeguards agreement is typical when it states that the objective of safeguards is the timely detection of the withdrawal of nuclear material from facilities at which safeguards are being applied except in accordance with the terms of the agreement. Conclusions are not, and cannot, be drawn at the state level about the absence of undeclared nuclear activities.

It should be emphasized that developing a SLA for NWS safeguards implementation has not been pursued to date. In addition, safeguards implementation at reprocessing and enrichment plants has not been adapted under integrated safeguards arrangements.[9] Except for plant specific adaptations, to date IAEA has sought to ensure uniform implementation of safeguards at enrichment and reprocessing facilities.

While the objectives and purposes of safeguards differ, to the extent that safeguards are applied at a multinational facility in a NWS, there are ways that a NWS SLA might be developed. These ways would be additional to whatever consideration would flow from the facility being a multinational enterprise. One way is to take into account in the structured analysis that is referred to above the fact of an existing nuclear weapon program in establishing safeguards priorities. The fact of these programs implies a lack of incentive to *divert* nuclear material from a safeguarded uranium enrichment facility or to produce excess low-enriched uranium (LEU) or high-enriched uranium (HEU) clandestinely. One way to take this into account would be to use less stringent goals for the inspection parameters of detection probability, timeliness of detection, or significant quantity. For example, a higher SQ might be considered as more appropriate.

One could also review the relevance or the weighting of the three IAEA objectives for enrichment plant safeguards:

- diversion of significant quantities of declared material
- excess production of LEU from undeclared feed
- production of enriched uranium with a greater than declared enrichment, particularly HEU

Of these, the second might be considered less pertinent than the others for a NWS where it operated at the same time an unsafeguarded uranium enrichment facility that was already producing LEU from "undeclared feed"—undeclared because the plant was not subject to safeguards. In the same vein, the first objective might be considered less pertinent than the third, both because the material would need further processing to manufacture a nuclear weapon and because of the presence of unsafeguarded stocks of similar material.

An alternative way is to adjust safeguards implementation or intensity would be to use factors that were seen as indicators of the commitment of the NWS to fulfill its NPT Article VI obligations. For example, one could take into account factors such as:

- the status of the nuclear weapon stockpile in a NWS and whether it was growing, was static, or was being reduced;
- whether nuclear material from nuclear weapons was being transferred to peaceful uses—downblending of HEU or use of Pu in reactor fuel.

In circumstances where it seemed clear that nuclear weapon stockpiles were diminishing or where nuclear weapon material was being converted to civil use, the priority attached to the third objective—production of HEU—might be reduced.

Conclusion

There is considerable interest in the use of international or multinational nuclear fuel cycle centers to help stimulate the growth of nuclear energy as a share of global electricity production. However this must be done in a fashion that promotes important nuclear nonproliferation objectives, especially by eliminating the need for states to develop their own sensitive nuclear technologies through assured access to necessary nuclear material. The dissemination of sensitive uranium enrichment technology by the A. Q. Khan clandestine network highlights the importance of this objective.

The Russian Federation has already established one such center that is structured to provide assured access through the combination of a joint stock company that is independent of state budgets; has access to enrichment services via contract with the AECC; and will have, further, a significant reserve of enriched uranium that is to be made available in case of a supply disruption. A key is that assured access is available to countries that do not develop their own uranium enrichment capacities.

Still, there are aspects of the IUEC that remain to be completed, especially, perhaps, the finalization of arrangement with the IAEA providing for the application of safeguards to IUEC nuclear material.

The IUEC is unique, but it calls attention to a number of issues that arise in the context of a multinational fuel cycle center, including some that apply to all such centers and some that apply to centers in a NWS.

It is clear that there remains considerable room for further development of these issues.

End Notes

1. See INFCIRC/640, 22 February 2005, *Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report,* submitted to the Director General of the International Atomic Energy Agency.
2. INFCIRC/708, June 8, 2007. Communication received from the resident representative of the Russian Federation to the IAEA on the Establishment, Structure, and Operation of the International Uranium Enrichment Centre.
3. Fact Sheet: Obama's New Plan to Confront 21st Century Threats, Chicago, Illinois USA, July 16, 2008 at http://www.barackobama.com/2008/07/16/fact_sheet_obamas_new_plan_to.php.

4. See INFCIRC/708, 8 June 2007, letter from the Permanent Mission of Russia on the *Establishment, Structure and Operation of the International Uranium Enrichment Centre* (which contained an attachment on *Establishment, structure and operation of the International Uranium Enrichment Centre*).
5. 2009. *Development of the Russian Federation Initiative to Establish a Reserve of Low-Enriched Uranium (LEU) for the Supply of LEU to the IAEA for its Member States,* GOV/INF/2009/1, February 23, 2009, Attachment, Page 5.
6. 2008. IAEA General Conference GC(52)/OR.1, Record of the First Meeting, Austria Center, Vienna, Monday, September 29, 2008, Items: 152-187.
7. Not all observers endorse the idea that multinational nuclear arrangements are necessarily positive. In at least one case, a participant in a multinational facility (Iran) was refused access to nuclear material for reasons other than strictly related to nuclear nonproliferation.
8. If the MNA reimbursed the IAEA for the work performed by IAEA staff, the total cost to the IAEA would be reduced.
9. According to the IAEA's "Research and Development Program for Nuclear Verification 2006-2007," integrated safeguards approaches for uranium enrichment facilities, MOX facilities, reprocessing plants, and HEU storage facilities remained to be "developed, tested, and approved."

New Verification Challenges

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This paper presents the personal views of the author and not necessarily those of the Australian government.

Abstract

To date, nuclear verification efforts have largely focused on International Atomic Energy Agency (IAEA) safeguards pursuant to the Nonproliferation Treaty (NPT). IAEA safeguards face a number of challenges, especially detection of undeclared nuclear activities—this will also be a major challenge for new verification missions, such as fissile material cut-off. In developing new verification missions, important lessons can be learned from IAEA safeguards experience. This paper briefly outlines some of the new verification issues and challenges on the horizon.

Introduction

Nonproliferation is not just an end in itself, but an essential contribution towards achieving a world free of nuclear weapons. This paper looks beyond the current International Atomic Energy Agency (IAEA) safeguards system, and briefly outlines the new verification missions required in support of this broader goal.

The maxim "trust but verify" is of fundamental importance to nuclear arms control–to efforts to counter the spread of nuclear weapons and ultimately to eliminate them. *Nonproliferation*—the commitment not to acquire nuclear weapons, and *disarmament*—the commitment to phase out and eliminate nuclear weapons—both depend on the highest levels of confidence and trust among states. Confidence and trust are underpinned by *verification*—effective verification is essential to achieving a denuclearized world.

To date, nuclear verification efforts have mostly focused on nonproliferation in the non-nuclear-weapon states (NNWS), in the form of IAEA safeguards. The negotiators of the Nuclear Nonproliferation Treaty (NPT) recognized that an effective nonproliferation regime is a necessary condition to achieving nuclear disarmament—disarmament will not proceed without confidence that new nuclear threats will not emerge. Moreover, an effective nonproliferation regime will be essential in the post-disarmament world, to counter new nuclear weapons programs, whether by former nuclear-armed states or others. Thus the nonproliferation regime will remain the essential foundation for nuclear disarmament—but its application will need to expand from the NNWS to the states that are currently nuclear-armed, i.e., the recognized nuclear-weapon states (NWS) and the states outside the NPT.[1]

The world has almost four decades experience with a comprehensive multilateral verification system, the IAEA safeguards system established pursuant to the NPT. By and large the IAEA safeguards system has proven successful, but it faces a number of challenges. The most serious of these is ensuring the capability to detect undeclared nuclear activities. Other safeguards challenges include: the potential spread of proliferation-sensitive technologies (enrichment and reprocessing) to further states; the implications of new fuel cycle technologies; and an ever-increasing workload.

These challenges impact on disarmament in two ways: through their implications for the effectiveness of the nonproliferation regime, essential to underpinning disarmament; and because there are parallel issues for disarmament itself—e.g., in the future, how will it be possible to reach credible assurance that none of the current nuclear-armed states has undeclared nuclear material and activities?

Progress beyond current nonproliferation arrangements will involve a range of new agreements and associated verification arrangements. There will not be a single disarmament treaty, but several steps: cut-off of production of fissile material for nuclear weapons; dealing with fissile material stocks; a ban on nuclear testing; reductions in the numbers of deployed nuclear weapons; dismantlement of nuclear weapons; stockpile stewardship issues; and so on. Each of these will involve particular verification challenges.

Verification Models[2]

The IAEA safeguards system has developed over some five decades, and represents the model in peoples' minds when they think about nuclear verification. Key features may be outlined as follows:

- a treaty-based commitment not to acquire or produce nuclear weapons, and to this end to accept verification measures on all nuclear material
- a multilateral inspectorate
- an obligation to declare all nuclear material and facilities to the inspectorate, and to maintain records and reporting
- ongoing inspections and other verification activities for declared material and facilities
- verification activities aimed at detecting possible undeclared material and activities—including information collection and analysis, detection techniques, and additional rights of access for inspectors

- inspections initiated by the inspectorate to investigate suspected treaty breaches
- compliance determination and enforcement procedures—the latter involving the UN Security Council

To some extent the institutional arrangements, approaches, and methods developed for IAEA safeguards will be adaptable to new verification missions. But novel situations are likely to require innovative solutions. Already there are alternative models that might influence future arrangements:

- mutual inspection—e.g., bilateral inspections, as is the case with the U.S./Russia nuclear arms control treaties;
- a regional inspectorate, such as Euratom and ABACC[3]—e.g., Euratom inspections apply to the civil nuclear programs of the two EU NWS (France and the UK)
- challenge inspections—an investigative inspection initiated by a party, as with the Chemical Weapons Convention (CWC) and the Comprehensive Nuclear Test Ban Treaty (CTBT)
- monitoring of technical data by the parties themselves, and ad hoc teams drawn from the parties for challenge inspections, as with the CTBT
- nuclear-weapon-free zones (most of which provide for alternative inspection arrangements if IAEA safeguards do not apply)

It is likely technical verification will need to be complemented by suitable transparency and confidence-building measures—see below.

IAEA Safeguards

IAEA safeguards issues are covered in detail by other authors and will be discussed only briefly here.

In the first two decades of the NPT, as the nuclear industry expanded, the focus of IAEA safeguards was on known (declared) nuclear materials and facilities. The IAEA developed a complex verification system, including: inspection, sampling, analysis, and monitoring methods; safeguards standards; safeguards equipment; and safeguards performance evaluation. Emphasis was placed on nuclear material accountancy, with containment and surveillance described as *complementary* measures. A particular interpretation of non-discrimination led to uniformity in safeguards implementation, resulting in inspection resources being concentrated in states with substantial nuclear programs regardless of any proliferation risk analysis.

Since the early 1990s, the illicit spread of sensitive nuclear technologies, especially centrifuge enrichment, has shifted attention to developing the capabilities needed for detection of *undeclared* nuclear activities. This has prompted fundamental changes in safeguards, including greater use of information, a broadening of verification activity, and the drawing of more qualitative conclusions. At the same time, the growth in workload and in complex facilities has led to containment and surveillance measures assuming greater importance.

Especially important has been the development of information-driven safeguards. Safeguards are moving from uniformity to a state-level approach, under which decisions on verification intensity can reflect state-specific factors. The state-level approach is essential to optimising effectiveness and efficiency, enabling scarce safeguards resources to be deployed to areas of highest priority.

The greatest technical challenge facing IAEA safeguards is establishing a reliable capability of detecting undeclared nuclear activities. The IAEA's technical skills are increasing—but the agency cannot be expected to find undeclared nuclear activities unaided. Member states have given the agency vital technical assistance in development of and training in equipment, detection technologies (such as sensors and satellite imagery) and so on. But more is needed in the area of information-sharing. States have substantial information, including intelligence ("national technical means") and export data (encompassing both items supplied and items denied).[4] Detecting undeclared nuclear activities—or providing credible assurance of their absence—requires an active partnership between the agency and states.

Other challenges for the IAEA safeguards system include: the potential spread of proliferation-sensitive technologies to further states; the consequences for safeguards of new fuel cycle technologies (leading to an increasing reliance on containment and surveillance relative to material accountancy); and an ever-increasing safeguards workload.

More than ever, it is essential for safeguards to be complemented by other nonproliferation measures, such as transparency and confidence-building mechanisms. These are discussed later in this paper.

New Verification Missions

Comprehensive Nuclear Test Ban Treaty

The CTBT prohibits all nuclear explosions, and establishes a verification regime to detect and investigate possible non-compliance. The treaty serves both nonproliferation and disarmament objectives—complementing the NPT by increasing the difficulty for a NNWS to produce reliable nuclear weapons, and limiting the ability of states with nuclear weapons to develop new warhead designs.

The treaty was opened for signature in 1996—to date it has been signed by 180 states and ratified by 148. It will not enter into force until ratified by the forty-four states listed in Annex 2 of the Treaty. Nine of these have yet to do so—China, DPRK, Egypt, India, Indonesia, Iran, Israel, Pakistan, and the United States.

Although the CTBT is not yet in force, the treaty stipulates that its verification regime must be capable of meeting the requirements of the treaty when it does enter into force. Most (more than 80 percent) of the treaty's international monitoring system (IMS) has been installed and is in provisional operation. The IMS will comprise 321 seismic, radionuclide, infrasound and hydroacoustic monitoring stations and sixteen radionuclide laboratories in eighty-nine states. IMS stations are operated by national agencies, mostly under contract to the Treaty organisation.[5] On-site inspection arrangements are also under development.

Conceptually CTBT verification is quite different to the IAEA safeguards model. Judgments on compliance, based on technical verification data, are made by the treaty parties themselves rather than the treaty secretariat. There are no regular inspections; rather, the IMS is looking for events that, it is hoped, will never occur. Hence there is no standing inspectorate. If an on-site inspection is required, an ad hoc inspection team would be drawn by the organization from a cadre nominated by the treaty parties. Data from the IMS stations are available to all treaty parties, via the organization's International Data Centre in Vienna. Any party therefore is in a position to analyse IMS data and to seek clarification of an event, including through an on-site inspection.

Despite concerns voiced by some in the United States about the CTBT's technical effectiveness, the IMS even in its partially complete state proved effective in the detection of the Indian and Pakistani nuclear tests of 1998 and the DPRK test of 2006. In addition, the IMS performed well with relatively small scale conventional explosions conducted in Kazakhstan for testing the system in 1999 (100 metric tons) and 2002 (12 metric tons). The main challenge for the CTBT is political, not technical—to gain the outstanding ratifications to enable the treaty to enter into force. U.S. leadership will be vital here.

Fissile Material Cut-off Treaty

The objective of the proposed FMCT is to ban production of fissile material for nuclear weapons and other nuclear explosive devices. The negotiating mandate agreed in the UN Conference on Disarmament (CD) is for the FMCT to be "non-discriminatory, multilateral, and internationally and effectively verifiable." Negotiations in the CD have been blocked for over a decade, but it is hoped statements by the Obama administration in support of a verifiable treaty will help break the logjam.[6]

Since negotiations have not yet commenced, the main provisions of the FMCT cannot be described with certainty. The principal area to be settled is the treaty's scope: which materials and facilities will be covered? As a minimum, the treaty would apply to new (i.e., post entry-into-force) production of fissile material. Verification would apply to:

- newly produced fissile material—likely to be defined as HEU (high-enriched uranium) and *separated* plutonium (i.e., not spent fuel)—to ensure it is not used for nuclear explosives; and
- facilities *producing* fissile material—enrichment and reprocessing facilities—to ensure that all production is declared.

Just how extensive the coverage of the treaty and the verification arrangements should be—whether there is a need to include other materials and facilities to ensure the effectiveness of the verification system—is yet to be determined. One area of contention is whether the FMCT should also apply to existing fissile material—the issue of stocks. Clearly stocks must be addressed, since otherwise the treaty's effectiveness in capping nuclear arsenals will be limited, but for the purposes of this paper it is assumed stocks will be the subject of further negotiations. Stocks are discussed further later in this paper.

Whatever the scope of the FMCT, it can be seen from the above outline that in concept the treaty should be similar to the current safeguards system:

- parties will be required to declare subject materials and facilities;
- an inspectorate will verify parties' declarations, records and reports;
- the inspectorate will also need to conduct verification measures for detection of possible undeclared material and activities;
- procedures will be required for investigation of suspected treaty breaches; and
- procedures will be required for compliance determination and enforcement.

The verification challenges for the FMCT are expected to be:

- having to implement verification approaches in old facilities not designed with verification in mind. These are likely to require intensive verification effort. The more of these facilities that can be shut down and decommissioned, the more manageable the verification task will be:
  - there will be no reason to continue operation of facilities used only for weapons programs (since the NWS have had informal moratoria on fissile production for weapons for many years, presumably no such facilities are operating now);
  - there should be little if any need to produce HEU (the states with large naval propulsion programs have extensive HEU stocks to draw on); and
  - with advanced spent fuel recycling technologies, which will avoid the need to separate plutonium such as pyroprocessing, on the horizon, there should be little or no requirement for new conventional (Purex-based) reprocessing plants, and existing plants could be phased out over time;
- the verification workload. This highlights the importance of shutting down as many sensitive facilities as possible, and transitioning to new fuel cycle technologies. A state-level approach, discussed below, will also be important for cost-efficient verification; and
- establishing a reliable capability for detecting undeclared fissile material production.

As with IAEA safeguards, detection of undeclared fissile material production will be a major challenge. It can be expected that the NWS have extensive information on each other's nuclear programs—sharing of information with the inspectorate will be essential. Unlike the current IAEA system, where information held by the Agency is confidential, there may well be a need for sharing of some kinds of verification information, as is the case with the CWC and the CTBT. Almost certainly formal verification activities will have to be complemented by transparency and confidence-building measures, possibly including mutual inspections and arrangements such as "Open Skies"—discussed later in this paper.

A mechanism for initiating investigative inspections will be required. Disappointment over the lack of use of the IAEA's special inspection mechanism—by which investigative inspections are supposed to be initiated by the agency—means states are unlikely to have confidence in such a mechanism. It is likely that a challenge inspection mechanism, which can be initiated by a party, will be required for the FMCT, either instead of, or as well as, inspections that can be initiated by the inspectorate.

One area requiring considerable development is that of verification standards and intensity for the FMCT. In the case of *horizontal* proliferation, the diversion of relatively small quantities of fissile material will be enough for a state to change its status from a NNWS to a nuclear-armed state. The sensitivity of IAEA safeguards—reflected in technical parameters such as goal quantities (e.g., the *significant quantity* of 8 kg plutonium), detection probability, timeliness goals, and inspection frequency—has been set accordingly.

For the states that already have nuclear weapons, however, the calculus is rather different. These states will be concerned about treaty violations that are of sufficient scale to alter strategic relativities: for a state with *hundreds* of weapons, it might take a violation of hundreds of kilograms to be strategically significant. On the other hand, for a state with a small arsenal—and the objective of disarmament is that all the NWS will progress to this situation in time—small-scale diversion will be significant. One approach that would meet both these cases is to regard a breakout equivalent to say 1 percent of the monitored inventory as a strategic change.[7] These considerations are likely to be reflected in the development of a state-level approach to verification, building on experience being gained with the state-level approach in IAEA safeguards. With a state-level approach, the technical verification objectives and parameters will be the same for all states, but decisions on verification intensity would take account of state-specific factors.

Relationship to Comprehensive Safeguards

It is envisaged that the FMCT will be a universal treaty, i.e., the parties will not be limited to the nuclear-armed states, but will also include the NNWS. In most respects the comprehensive safeguards agreements (CSAs), which NNWS conclude under the NPT should be sufficient to meet the requirements of the FMCT, and additional verification should not be necessary.

However, negotiation of the FMCT provides an opportunity to address some important issues facing the IAEA safeguards system. For example, a concern with NPT safeguards agreements is that their duration is tied to the state's membership in the NPT. If the state withdraws, the CSA lapses. Consideration could be given in the FMCT to an *irreversibility* provision, that once nuclear material and facilities become subject to peaceful use commitments they would retain this status in perpetuity. Another improvement over current CSAs would be introduction of a challenge inspection mechanism.

Fissile Material Stocks

Irreversible submission of excess fissile material stocks to a verified commitment against explosive use will be essential to complement the proposed FMCT and further disarmament steps. As long as there remain significant fissile stocks outside any such commitment that can be drawn on to produce new nuclear weapons, there will be concerns about the durability of limits on the number of weapons. If excess stocks are not covered by the FMCT—they are not included in the current negotiating mandate—a further agreement covering stocks will be needed in due course.

In general there are no particular verification challenges with stocks, other than workload. Parties will declare fissile stocks they regard as excess to military requirements, and these would be verified–initially and on a continuing basis. While these stocks might be stored for a period, it is expected that in due course they would enter the civil fuel cycle, or would be conditioned for disposal. Since the declarations would be voluntary, there would be no requirement for verification activities to establish the completeness of the declarations (i.e., that there are no undeclared materials). However, as a transparency measure, the nuclear-armed states might declare the quantities of fissile materials they hold outside verification.

Subsequent Steps

The verification task becomes more complicated if it is decided, as disarmament progresses, that the nuclear-armed states should declare and submit to verification *all* fissile material except material in the form of declared nuclear weapons. This would raise two issues:

- the need to declare and verify fissile material in non-proscribed military use, e.g., naval propulsion. This is discussed in the next subsection.
- the need for verification measures to ensure completeness, i.e., that there is no undeclared fissile material. This is discussed further later in this paper.

Naval Propulsion Programs

This is raised as a problem for FMCT, but it is also a potential problem for current IAEA safeguards. CSAs allow NNWS to remove from safeguards nuclear material intended for non-proscribed military use, under arrangements to be agreed with the

IAEA.[8] For CSAs, this provision has not been put to the test, as to date no CSA state has introduced nuclear naval propulsion, but Brazil has indicated an interest in acquiring nuclear-powered submarines.[9]

Some NWS operate naval reactors with HEU fuel, so there is the possibility that HEU production could continue under the FMCT for this non-proscribed military purpose—although it would be an advantage in terms of verification tasking if the states concerned concluded that their existing HEU stocks were sufficient and they had no need for ongoing HEU production.

The problem for verification arises because states with naval reactors regard the design of naval fuel, and factors such as core loadings and range between refuelling, as highly classified. While concern about security is understandable, it is essential to develop appropriate verification arrangements so that naval programs don't present an opportunity for diversion. Diversion is not an issue just for HEU fuel—because LEU could be used as feedstock for high enrichment in an undeclared facility, verification arrangements would also be needed for LEU-based naval programs. And, as noted above, the need for verification might apply not only for new production for naval programs, but for existing HEU stocks.

Because of the sensitivities, verification for naval programs will require novel approaches. However, the problems are not insurmountable—the *Trilateral Initiative*[10] between the United States, Russia, and the IAEA demonstrates the practicability of innovative approaches to verifying fissile material of sensitive composition, shape and mass. Formal verification may be complemented by transparency arrangements, e.g., it is easy to check that a vessel is at sea (and therefore has been fuelled).

Stockpile Stewardship Activities

A complication for FMCT is that some nuclear-armed states may require to recycle plutonium from nuclear weapons—either to remove the build-up of americium-241[11] (a practice known as clean-up), or to manufacture new weapons (it is not expected that FMCT would prohibit production of new weapons from fissile material in existing weapons). In the past, NWS have simply withdrawn warheads as they reach the end of their service life and produced further plutonium to replace them (one reason why the NWS have accumulated so many warheads), but under FMCT this will no longer be an option.

Verification measures for FMCT will need to be able to distinguish between recycle of existing plutonium and new separation of plutonium from irradiated fuel or targets—new separation for weapons would be prohibited. For national security reasons, access to recycle facilities will not be allowed. But measures such as sampling of gaseous emissions would readily indicate if new separation was being undertaken.

Nuclear Weapon Reductions and Dismantlement

The United States and Russia have substantial experience with mutual verification of numbers and class of deployed strategic warheads, though to date these agreements have dealt with delivery systems rather than weapons as such. Nonetheless, this experience can be applied to new arrangements to verify declarations, where numbers of weapons deployed or stored are declared, and numbers of weapons to be dismantled are declared. Far more challenging would be verification measures for completeness of declarations, i.e., that there are no *undeclared* nuclear weapons. This is touched on in the next section.

While there is no direct experience of verifying dismantlement—that weapons committed for dismantlement are in fact dismantled and the fissile material placed under non-explosive/verification commitments—verification requirements have been studied in the United States,[12] and are currently under study by the UK and Norway.

Conceptually, what is required is continuity of knowledge (or *chain of custody*) over the item being dismantled and its fissile core. Verification elements would include:

- a specially constructed dismantlement facility, the integrity of which is regularly reverified;
- monitoring to ensure inspectors are aware of all items entering and leaving the facility; and
- instruments and procedures for confirming that fissile material within defined parameters of mass and isotopic composition has been submitted to the verification process.

The Trilateral Initiative, mentioned previously, has demonstrated that fissile material can be satisfactorily verified against unclassified attributes without revealing sensitive information to inspectors.

Following dismantlement, the fissile core will need to be processed to alter mass, shape and probably isotopic composition, e.g., by blending in a facility under black box arrangements. This will require knowledge of all materials entering and leaving the process area. There will be complexities—e.g., how to ensure that information on inputs of unclassified blending material doesn't allow calculation of sensitive details of the weapons material—but the problems are not insurmountable.

Verification Measures Against Undeclared Fissile Material

Today nuclear-armed states are not required to declare military fissile material holdings, but this will be required as disarmament progresses—raising the issue of how to ensure that declarations are complete. Detection of possible undeclared fissile material holdings is by far the greatest verification challenge, particularly in the NWS where nuclear weapon programs have operated for decades and have involved many facilities and large quantities of nuclear material.

There is some experience with verifying that all nuclear material in a weapon program has been accounted for, when

South Africa renounced nuclear weapons and joined the NPT in 1991. The South African program had been very small—only six nuclear weapons, using HEU, had been produced. The IAEA's verification that all nuclear material was accounted for is regarded as a success, but the practical difficulties of achieving accuracy were significant.

Conducting such an exercise with much larger programs will be very difficult. This is illustrated by the historical study of plutonium production in the U.S. military program, published in 1996.[13] This study showed "inventory differences" of some 2,800 kg, or 2.5 percent, in military plutonium accounts over the period 1944–1994. These differences were mainly attributed to measurement uncertainties, and 68 percent of the differences occurred in the period prior to the late 1960s.

A similar study was conducted by the UK and published in 2000.[14] This study concluded that "Overall, confidence in the completeness and accuracy of the information available is very high for the 1980s and 1990s, but less so before the mid 1960s." The study found a discrepancy of 290 kg of plutonium, or 1.7 percent, between recorded movements into and out of the Atomic Weapons Establishment at Aldermaston. In fact this discrepancy was a surplus—more plutonium was found than expected—but the error margin shows the difficulties of establishing accurate nuclear accounts for historical periods.

It could be some time before verification of the absence of undeclared warheads or fissile material in the NWS becomes critical. By then it is to be hoped that transparency and confidence-building amongst these states will have progressed to the extent needed to provide confidence in the formal verification results.

Transparency and Confidence-Building Measures[15]

There are limits to what verification can deliver—e.g., verification cannot provide definitive assurance about a state's future intent; and it is difficult to prove a negative, i.e., to verify the absence of undeclared nuclear material and activities. Accordingly, technical verification measures are not likely to be sufficient in themselves to build the required confidence as disarmament proceeds. It is likely technical verification will need to be complemented by suitable transparency and confidence-building measures.

The purpose of such measures can be described as "to introduce transparency and thereby predictability in relations between states by clarifying national intentions, reducing uncertainties about national activities, and/or constraining national opportunities for surprise."[16] These measures can be grouped as follows:

- information and communication
- observation and inspection
- reciprocally imposed constraints

There is insufficient space here to discuss the range of possible confidence-building measures. Proposals for further strengthening the nonproliferation regime, which will also be relevant to the nuclear-armed states as the process of disarmament proceeds, include:

- full cooperation with IAEA safeguards (or other verification process);
- limiting the spread of sensitive nuclear technologies
- greater commercialisation and globalisation of nuclear activities—moving away from wholly national programs, and particularly government-run programs;
- regional collaboration on nuclear programs
- multilateralisation of the sensitive stages of the fuel cycle—including establishment of multinational fuel cycle centers; and
- development of proliferation-resistant technologies

Transparency and confidence-building arrangements will need to be negotiated among the parties most concerned, and may be specific to particular bilateral or regional situations. Possibilities could include:

- a Middle East nuclear-weapon-free zone where *inter alia* all parties forego enrichment and reprocessing, and mutual inspections as well as IAEA inspections apply; and
- an ABACC-type arrangement between India and Pakistan.

Conclusion

A number of the prospective new verification missions discussed here are analogous, technically, to IAEA safeguards—although the sensitivity of some of the materials and facilities will require innovative approaches, as seen already with the Trilateral Initiative. In establishing new verification arrangements it will be important to draw on IAEA experience to the extent appropriate.

As new kinds of agreements are negotiated, the parties will need to address not just technical aspects but also institutional arrangements. Issues to be considered include:

- agreement organization—the parties may prefer executive and decision-making organs that are designed specifically for the particular agreement, rather than add to the IAEA's responsibilities;
- inspection arrangements—the IAEA inspectorate might perform inspections under new agreements, or may serve as a model for new multilateral inspectorates. But other models are possible, including mutual inspections or regional inspections;
- availability of information—the parties might wish to see a freer flow of verification information to parties than is allowed under the IAEA's current confidentiality rules;
- actionable information—inspections provide the means of resolving suspicions, it could be counterproductive to set the bar too high. Compared with IAEA practice, parties may wish a less rigorous model for triggering inspections, provided there is a filter against frivolous or vexatious requests.[17] An example might be *societal* verification—usually thought

of as whistleblower information, but could also include, e.g., NGOs monitoring satellite imagery; and

- investigative inspections—the parties are likely to want a challenge inspection mechanism that can be initiated by a party.

As discussed above, transparency and confidence-building mechanisms are expected to have an essential role in complementing formal verification arrangements.

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Notes

1. In this paper, unless otherwise indicated, the term "nuclear-armed" is used to cover both the NWS and the non-NPT states.
2. For a more detailed analysis of IAEA safeguards relative to other treaty verification systems see the author's article, 2006. Experience and Challenges in WMD Treaty Verification: A Comparative View, *Verifying Treaty Compliance.* R. Avenhaus, Springer, Berlin, 2006.
3. Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials.
4. Knowledge of procurement attempts can be invaluable to the IAEA's understanding of a state's nuclear program, declared or otherwise.
5. Currently the Preparatory Commission for the CTBT Organization.
6. For a discussion of FMCT verification issues see the author's article, 2004. Can a Fissile Material Cut-Off Treaty be Effectively Verified? *Arms Control Today*.
7. The 1 percent figure was informally adopted in the Trilateral Initiative.
8. See INFCIRC/153 paragraph 14.
9. Canada considered nuclear-powered submarines in the 1980s but did not proceed.
10. See e.g., Shea, T. E. 2008.The Trilateral Initiative: A Model for the Future? *Arms Control Today.*
11. Pu-241, with a half-life of 14.4 years, decays to Am-241.
12. See e.g., Gerdes, E. R., R. G. Johnston, and J. E. Doyle. 2001. A Proposed Approach for Monitoring Nuclear Warhead Dismantlement, Science and Global Security, Vol. 9.
13. 1996. *Plutonium: The First 50 Years,* U.S. Department of Energy.
14. 2000. *Plutonium and Aldermaston—An Historical Account,* UK Ministry of Defence, 2000.
15. For a discussion of transparency in IAEA safeguards, see Larrimore, J., M. Kratzer, J. Carlson, and B. Moran. 2006. Transparency and Openness: Roles and Limitations in the Nuclear Nonproliferation Verification System, *Journal of Nuclear Materials Management,* Vol. 35, No. 1.
16. Definition suggested by United Nations Institute for Disarmament Research (UNIDIR).
17. Under the CWC (Art. IX.17) an inspection can be disallowed by a 3/4 vote of the Executive Council.

When is Noncompliance, Noncompliance?

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Abstract
When is noncompliance, noncompliance? The International Atomic Energy Agency (IAEA) must address this question in regard to the Nuclear Nonproliferation Treaty. Instead of defining compliance in itself, this paper proposes a three-step compliance process: (1) develop a framework for evaluating intent, (2) grant the IAEA the legal authority to inspect suspected nuclear sites in a timely manner, and (3) invest in state-of-the-art technology for verification. These three steps can be integrated to draw conclusions on a nation as a whole. This process will give the IAEA the flexibility to adapt to a wide range of compliance issues.

Introduction
Nico Jacobellis was the manager of a movie theater in Cleveland Heights, Ohio USA. In 1964, he showed the Louis Malle film *The Lovers,* which was advertised as the "most daring love story ever filmed." Under Ohio law, Jacobellis was convicted of exhibiting an obscene film. He briefly became the focal point of a national debate over the definition of obscenity when his case went to the Supreme Court. In the ruling that reversed the judgment, Justice Potter Stewart famously wrote, "I shall not today attempt further to define the kinds of material I understand to be embraced within that shorthand description; and perhaps I could never succeed in intelligibly doing so. But I know it when I see it."[1]

Just as the U.S. Supreme Court struggled to define obscenity in 1964, the International Atomic Energy Agency (IAEA) struggles today to define noncompliance. Both terms are subjective in nature, skewed by perceptions, cultural norms, and politics. Despite its ambiguity, it is important for the international community to address the issue of noncompliance with the Nuclear Nonproliferation Treaty (NPT). Without a robust system for declaring noncompliance, what does a would-be proliferator stand to lose?

The dual nature of the NPT as a treaty that simultaneously attempts to prevent the spread of nuclear weapons technology and spread peaceful nuclear technology complicates the compliance issue. It is a textbook case of the political saying, "Where you stand depends on where you sit." On one hand, some states want to focus on Articles II (the obligation not to develop or receive nuclear weapons) and III (safeguards) of the NPT. On the other hand, some states that prefer to focus on Articles IV (technical cooperation) and VI (disarmament).[2] Assessing compliance with the NPT requires balancing this fundamental tension in the treaty. Any move to strengthen the compliance mechanism with one half of the treaty will require an equal move to strengthen the other half for the treaty to remain acceptable to nuclear weapons states as well as non-nuclear weapons states. This paper focuses on compliance with Articles II and III of the NPT.

Article XII of the IAEA statute lays out the procedure for dealing with safeguards noncompliance.[3] Inspectors report any noncompliance to the director general, who passes the information to the Board of Governors. The board then calls upon the state to take corrective action. The Board also reports the noncompliance to all members and the Security Council and the General Assembly of the United Nations. If the state fails to remedy the compliance issue, the Board may call upon the agency to suspend member privileges to that state. There are not, however, clear guidelines on what constitutes noncompliance.

The adoption of the Additional Protocol (INFCIRC/540) has gone a long way in allowing the IAEA to assess the full picture of what is going on in each state.[4] It has given inspectors more information on things such as nuclear-related imports and exports as well as greater rights of access. It also grants the IAEA the right to look for possible undeclared nuclear facilities. The Additional Protocol strengthens the agency's ability to resolve suspicions of noncompliance, but it has not been signed and brought into force by all member states. Universality of the Additional Protocol will likely make questions of noncompliance easier to judge.

One way to address the issue is to list a set of conditions that bound compliance and judge each country purely on a checklist of obligations. This kind of approach depoliticizes the compliance judgment, thus helping the agency maintain its legitimacy as an impartial body. While it is the most objective approach, it does not account for the nuances inherent in each individual case. It can also create tunnel vision, wherein inspectors focus solely on checklist items instead of paying attention to the whole picture. An alternative is for the IAEA to define the process for evaluating compliance instead of compliance in itself. The process proposed in this paper has three steps: evaluate, inspect, and verify. Elaborating, these are (1) develop a framework for evaluating intent, (2) grant the IAEA the legal authority to inspect suspected nuclear sites in a timely manner, and (3) invest in state-of-the-art technology for verification. By not establishing a rigid definition of noncompliance, the IAEA will have more flexibility to adapt to a changing world.

Evaluating Intent

Intent is a concept even more elusive than compliance. It is hard to judge and even harder to prove, and like most interesting questions in life, the answer is not black-and-white. That being recognized, it does not mean that evaluating intent should be avoided because it is difficult. It simply means that there are limitations to the certainty that can be placed on an evaluation of intent. The state-level approach (SLA) envisions optimizing quantitative and qualitative data to tailor the safeguards implementation for a particular member state. In drawing conclusions about compliance, the intent evaluation can be seen as just another layer in the state-level profile of a country. Because technology cannot discern intent, the optimization problem for a compliance assessment would combine quantitative and qualitative data as well as judgment and analysis.

To aid in making such a determination, it is useful to have a transparent and defensible framework on which to characterize intent. This allows judgments to be made with some level of consistency. One such framework has already been developed by Seward, Mathews, and Kessler.[5] They identified indicators of peaceful and nonpeaceful uses of nuclear technology, which were broken down into four categories. They consider a state's nonproliferation credentials, fulfillment of Article III obligations, the coherence of their nuclear energy program, and their geopolitical cooperation. Weaponization activities can also be added to the list.

Nonproliferation credentials are straight-forward indicators and refer a state's participation in the NPT or other regional safeguards regimes. To evaluate a state's fulfillment of Article III obligations, factors such as ratification of the Additional Protocol, the effectiveness of their State System of Accountancy and Control (SSAC), and their level of cooperation with inspectors can be assessed. Are there patterns of Article III violations? Are they suggestive of unintentional errors or deliberate offenses? Also included in this category is the presence of undeclared facilities. In some cases, facilities may not only be undeclared but also disguised to look like something else. Iran used deception and denial techniques to hide its uranium enrichment facility at Natanz. More recently, the alleged reactor building at the al Kibar site in Syria was built to look like a Byzantine fortress.[6] The coherence of a state's nuclear energy program can also show indication of peaceful or nonpeaceful use of nuclear technology. For instance, intent can be gauged on whether fuel cycle facilities within a state are economically reasonable. Reports have indicated that Iran may be running out of uranium while lacking adequate resources to fuel even one Bushehr-type reactor. In addition, the United Nations Security Council has banned Iran from importing uranium ore. The discrepancy between Iran's stated intentions and its capabilities brings into question the coherence of its nuclear energy program. If Iran's intent is an indigenously fueled nuclear energy program, it will either need to put additional resources into its uranium mining industry or work out its differences with the international community so that it can import uranium.[7] Other indicators in this category include procurement patterns and security measures that are inconsistent with a civil nuclear program. Furthermore, has the state violated export control regulations? The fourth category for evaluating intent is geopolitical considerations. The stability of the region where a state is located influences security requirements. Membership in other international nuclear treaties such as the Nuclear Safety Convention or membership in the Nuclear Suppliers Group may be indicators of peaceful intent. Finally, weaponization activities can be used to demonstrate intent. This includes research funded within a state in areas such as high explosives development, hydrodynamic tests, and fissile material experiments.[8]

Beyond the indicators spelled out in the framework, analysts may run into unforeseen factors that play a role in the evaluation. In these cases, common sense and special consideration should be applied. Once the relevant information for the framework is gathered, red-teaming exercises can be introduced into the evaluation process. This type of exercise can help analysts understand the complex security and economic interests of a state. It should be reiterated that the evaluation of a state's intent plays a critical but limited role in the overall assessment of compliance with the NPT. The intent analysis should be integrated with all the other tools available to the IAEA so that a complete snapshot of a state's compliance record can be assessed.

Timely Inspections

The best way to address suspicions or allegations of noncompliance is through inspections. Because of this, it is important for the IAEA to have the legal authority to conduct inspections in a timely manner. Two mechanisms the Agency has at its disposal are special inspections and complementary access.

Under comprehensive safeguards agreements (INFCIRC/153), the IAEA is permitted to conduct special inspections.[9] Specifically, paragraph 73 gives the IAEA authority for special inspections in the case that information provided by the state is not adequate for the Agency to fulfill its responsibilities to ensure safeguards are applied to all nuclear material in peaceful nuclear activities. These inspections may involve access to locations outside of those included in routine and ad hoc inspections.

In 1992, the Board of Governors agreed that special inspections should only be used on "rare occasions," but it is important to note that a request for one does not imply some wrongdoing. The 1992 special inspection in Romania was undertaken to clarify matters that took place under the previous political regime.[10] Before the agency can perform a special inspection, it is required to consult with the state over the circumstances in question. There is not, however, a time limit on the consultation process. Theoretically, a noncompliant state can stall for time with the consultation process while it destroys any incriminating evidence. This is the major weakness of the special inspections tool.

Complementary access is one of the measures permissible in states party to the Additional Protocol. It remedies the timeliness issue of special inspections by allowing short-notice access to all buildings on a nuclear site. Advance notice is twenty-four hours in most cases, but only two hours is required for access in conjunction with design information verification or ad hoc or routine inspections. Complementary access is designed to ensure the absence of undeclared facilities or clear up inconsistencies in state-provided information. Activities during complementary access may include examination of records, visual observation, environmental sampling, utilization of radiation detection and measurement devices, and the application of seals and tamper-indicating devices. The major drawback of complementary access is that it only applies in Additional Protocol states.

There is a loophole in the system designed to allow inspectors to investigate questions of noncompliance. According to INFCIRC/153, the objective of safeguards is the timely detection of diversion of significant quantities of nuclear material. Without the proper legal authority for inspectors to access nuclear sites in a timely manner, the integrity of the safeguards system is undermined. Building on the legal authorities already in place, there are two options for closing this loophole. These are (1) amend the special inspections authority to include a time limit on consultation or (2) make the Additional Protocol mandatory for all NPT signatories. A third option would be to mandate a new authority for emergency inspections. Whichever route the IAEA chooses, having the legal authority to conduct inspections in a timely manner is an important aspect in the compliance process.

The Role of Technology

Technology is the bridge that connects verification and compliance. It is essential for building confidence between NPT member states and maintaining the credibility of safeguards conclusions. The role of technology is constantly evolving to meet new challenges. Today the IAEA is faced with a growing number of nuclear facilities but a fixed number of inspectors. This strain on resources means that safeguards technology has to be more effective and efficient than ever before.

The IAEA is adapting to the changing landscape by transitioning to a more information-driven system. Information management is a key area for advancement in the new verification culture. In many cases, there is an overwhelming amount of information to be processed. Data mining algorithms and knowledge extraction engines may be useful for delving deeper into large data sets and filling in knowledge gaps. Also, proliferation can happen over decades. Trend analysis tools can look at facilities in space and in time. When these types of algorithms are developed into analysis-friendly software packages, they can become very powerful tools for analysts.

Solutions often do not work individually but rather need to be integrated to extract useful information. Tools are needed that can integrate data from various sources. By combining technologies, the agency can optimize the strengths of each technology while minimizing their weaknesses. For example, a lot of effort goes into closing uncertainty gaps in radiation detectors. If those detectors are combined with cameras, seals, and radio-frequency identification (RFID) tags, the uncertainty gap becomes less important. Integration and optimization will play a big part in improving safeguards efficiency and effectiveness.

Ideally, safeguards systems would be designed into new facilities. One of the lessons learned from Rokkasho Reprocessing Plant is that systems need to be designed at the plant level. The plant conceptual design should drive things such as instrument design and data authentication protocols, not the other way around. It is much harder to go in after the fact and get a patchwork of smaller systems to function coherently. Standardization and interoperability will also lead to more efficiency. One of the keys to making this happen is communication. The IAEA needs to communicate their technology needs and research institutions need to bring in commercial vendors early to minimize reengineering.[11] Facility managers need to be brought into the loop, as well. If the safeguards systems are too expensive or intrusive, there will be no facilities to safeguard.

Finally, the IAEA has broadened the scope of its activities following the discovery of clandestine nuclear facilities in Iraq in 1991. This raises the question of whether the discovery of an undeclared facility is enough to warrant a charge of noncompliance. It is a big step to go from detecting an undeclared facility to detecting weaponization.[12] Going back to INFCIRC/153, the objective of safeguards is not limited to diversions of nuclear material for nuclear weapons purposes but also diversion "for purposes unknown." Thus, the existence of an undeclared nuclear facility constitutes noncompliance with a state's comprehensive safeguards agreement, which may imply a de facto act of noncompliance with Article III of the NPT. If combined with an evaluation of intent that points to a nuclear weapons program, it may also demonstrate noncompliance with Article II.

Technology plays an enormous role in detecting undeclared facilities. Commercial satellite imagery and environmental sampling have emerged as the most powerful technologies thus far and will continue to be mainstays in detecting undeclared facilities. It should be recognized that as satellite imagery becomes increasingly ubiquitous, would-be proliferators will also become increasingly better at masking their activities.

As the nuclear industry continues to grow, the scientific community will be faced with a new set of challenges. For instance, what will the signatures be of next generation nuclear facilities? Will the IAEA play a role in a Fissile Material Cut-Off Treaty? Can the IAEA help unravel proliferation networks? It is difficult to overstate the role of technology in these endeavors. Machines do not have political biases, personal agendas, or hold grudges. In other words, technology is objective. Technology will continue to play a major role in verifying that states are upholding their NPT obligations.

Conclusions

Just as Justice Stewart refrained from defining obscenity in 1964, the IAEA should refrain from defining compliance. There is no one-size-fits-all solution to noncompliance. While a rigid definition of compliance would allow the IAEA to remain apolitical, the context and severity of each case is also important. Instead, the IAEA should think of compliance as a process. The process proposed here consists of three elements. The first of these is the evaluation of intent. A transparent and defensible framework for evaluating intent should be developed. Next, the IAEA should have the legal authority to conduct timely inspections. Inspections are the fastest way to address suspicions of noncompliance. Special inspections and complementary access are sufficient for clarifying most questions or inconsistencies, but there is still a loophole that allows states to circumvent timely inspections. Finally, the IAEA must be able to verify that states are fulfilling their NPT obligations. State-of-the-art technology is unmatched in its ability to provide objective answers to questions about the facts. The IAEA should do everything it can to ensure it stays at the forefront of technology.

The three steps—evaluation, inspection, and verification—can be integrated to draw conclusions on a nation as a whole. Establishing a robust process for the determining compliance is important for maintaining the legitimacy of the NPT. How the IAEA deals with compliance issues today will have a resounding effect on the future of the NPT.

Karen Miller is a Ph.D. candidate in the Nuclear Security Science and Policy Institute at Texas A&M University. She has a B.S. in nuclear engineering from Texas A&M University. Currently, Miller is working on her dissertation with the Nuclear Nonproliferation Division at Los Alamos National Laboratory. She is also one of the founding members and former president of the Texas A&M Student Chapter of the INMM.

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Nuclear Safeguards, Security and Nonproliferation: Achieving Security with Technology and Policy

By Leslie G. Fishbone
JNMM Associate Editor for
Nonproliferation and Arms Control

Nuclear Safeguards, Security and Nonproliferation: Achieving Security with Technology and Policy

James E. Doyle, Editor. Butterworth-Heinemann, an imprint of Elsevier, Burlington, Massachusetts, USA and Oxford UK. 2008.

ISBN: 978-0-7506-8673-0

As soon as I glimpsed the table of contents of *Nuclear Safeguards, Security and Nonproliferation: Achieving Security with Technology and Policy,* I knew I needed to read it to fill in the gaps in my knowledge of modern safeguards methods and of case studies of countries where the nonproliferation regime either was violated or was adopted after some difficulty. I was very satisfied with these parts of the book, which is in fact an anthology with contributions from many experts. James Doyle deserves congratulations for shepherding this anthology to fruition. It fills a void in the literature and will be very useful in the several university-level courses currently being taught.

Heavily oriented toward international issues, the subjects addressed in the book are entwined with the activities of the International Atomic Energy Agency (IAEA). Chapter authors have worked at the IAEA, national laboratories, government agencies, universities, non-government organizations, or some combination.

The anthology will be generally accessible to readers with a policy orientation as well as those with a technical orientation. However, there are a few technical chapters that will probably strain the abilities of the former, particularly the chapter about a model for attribution of terrorist nuclear attacks and the chapter about statistics.

I found most interesting two groups of chapters. The first group comprised those chapters describing the newest methods employed by the IAEA and other organizations that focus on international nuclear safeguards and nonproliferation. These methods are open source reviews for proliferation indicators, commercial satellite imagery, nuclear test monitoring, and evaluating nonproliferation *bona fides.* The last is particularly intriguing: just what combination of factors leads to a probable conclusion that a country is or is not maintaining its commitment not to proliferate?

Unfortunately, there is no chapter on environmental sampling, an important technique in modern safeguards.

The second group of chapters of particular interest to me describes case studies based on the methods. There are chapters about facilities in Kazakhstan, Japan, and the Democratic People's Republic of Korea (DPRK; North Korea); about major nonproliferation decisions in South Africa, Argentina, and Brazil, and Libya; and about the A. Q. Khan proliferation network. There is also an extended case study of Iran in the chapter about commercial satellite imagery.

One chapter on nuclear material measurement technologies is encyclopedic in its coverage of nondestructive assay, and it appropriately includes many photographs and diagrams of equipment. This chapter describes active and passive assay, based on gamma rays and neutrons, and calorimetry. Two other relevant general references would be useful companions to the one cited by the authors; they are T. Gozani, *Active Nondestructive Assay of Nuclear Materials, Principles and Applications,* NUREG/CR-0602 (U.S. Nuclear Regulatory Commission, Washington, DC, 1981) and *Handbook of Nuclear Safeguards Measurement Methods,* D. R. Rogers, Ed., Mound Laboratory report MLM-2855, NUREG/CR-2078 (U.S. Nuclear Regulatory Commission, Washington, DC, 1983). The latter includes material on bulk measurements, the necessary complement—for material balance purposes— to destructive or nondestructive assays that yield concentration only.

In a short section about handheld gamma ray instruments in this nuclear measurement chapter, there is a very damning characterization of the aggregate performance of seven nuclide identifiers designed for screening people and cargo: "…lumped together, the number of correct identifications, the number of false positives, and the number of false negatives were approximately equal." This leaves much room for progress.

Another chapter addresses irradiated fuel measurements. In this chapter's discussion of reactors, that produce the irradiated fuel, there are no diagrams to elucidate the different reactor types mentioned. They do appear in another book that would be an excellent reference for this chapter, A. V. Nero, Jr., *A Guidebook to Nuclear Reactors* (University of California Press, Berkeley and Los Angeles, CA, 1979).

Physical protection systems (PPSs), one of the important overlapping features of a well-designed safeguards system, are discussed very succinctly by Mary Lynn Garcia, who authored an entire book devoted to PPS: *The Design and Evaluation of Physical Protection Systems,* 2nd ed., (Butterworth-Heinemann, 2007). There should be a direct and clear reference to that book, not just to one chapter as is given in a footnote. There should also be an illustrated example, however simple, of the PPS analysis described in Figure 1. After all, nuclear security is one of the title subjects of the book under review.

Evaluation of the quality of its international verifications is important to knowing how well the IAEA performs its mission. This is true whether the IAEA is carrying out safeguards in countries with comprehensive safeguards agreements (CSAs) only, in states with CSAs and an additional protocol, or in states with other safeguards agreements. This subject of evaluation is nicely summarized.

There finally are chapters addressing nuclear terrorism and radiological threats, and the export controls, customs operations, and field detection methods to address these threats. In connection with these discussions, an illuminating video dramatization is *Last Best Chance,* produced with support from the Nuclear Threat Initiative, and additional funding from the Carnegie Corporation of New York and the John D. and Catherine T. MacArthur Foundation.

As professionals, we are obliged to state the facts as best we know them and give reasonable inferences. But wording is important, so need we make such a statement as this, which appears early in the chapter about radiological dispersal devices (RDDs)? "The initial public response to an RDD attack will nearly certainly cause public panic, irrespective of the amount and type of radioactive material actually dispersed." In my opinion this type of statement might induce the very reaction that should be avoided. Better to say something like this: "Since an RDD attack is not an event about which society has any experience, the initial public response will depend critically on prior education and the ability of authorities to provide guidance concerning the actual risk and means to mitigate it." And then, of course, promote public education.

The book would have profited from a succinct exposition of the history of nuclear weapons acquisition, proliferation, and nonproliferation—perhaps by a timeline. Absent such an exposition, it requires very careful reading to find a mention of the nuclear explosive test by the DPRK that took place on October 9, 2006, after it withdrew from the Treaty on the Nonproliferation of Nuclear Weapons (NPT) in January 2003; the book was published in 2008. The mention occurs in the chapter on nuclear test monitoring. There is no mention of it in the chapter on decommissioning the DPRK facilities.

For a second edition, there should be a unified list of recommended general references in addition to the detailed chapter footnotes. A table of units is always helpful in a book with technical material. And if the book is to be used as a class textbook rather than just as a descriptive anthology, there should be questions for discussion and exercises at the ends of the chapters. Of course the occasional mistakes would need to be corrected.

There are two problems associated with the writing of the chapters by many different authors. One is that there are duplications in coverage of certain topics. The second is that useful cross-referencing between chapters is rare. But these are the inevitable consequences of an anthology, to which specialists in many fields need to contribute to achieve wide and timely coverage, that needs to be finished and published to achieve its important purpose: education.

An example of the second problem is that a footnote in the chapter about evaluating international safeguards systems directs the reader to an IAEA document for the table of significant quantity values. But the reader need look no further than the first table in the chapter about international safeguards inspections.

To summarize, Doyle's anthology is a very good and timely book on a subject of critical importance to national and international security. It covers a range of specific subjects under the rubric of its title and does so very well. Since nobody can be expert in all of the subject areas, this book belongs on the bookshelf of all current practitioners. With supplementary material, it can also serve well as a text for courses. I strongly recommend it.

U.S. DOE Announces Funding for 71 University-Led Nuclear Research and Development Projects

In May, the U.S. Department of Energy (DOE) announced the selection of seventy-one university research project awards as part of its investments in cutting-edge nuclear energy research and development (R&D). Under the Nuclear Energy University Program (NEUP), these seventy-one projects will receive approximately $44 million over three years to advance new nuclear technologies in support of the nation's energy goals. By helping to develop the next generation of advanced nuclear technologies, the Nuclear Energy University Program will play a key role in addressing the global climate crisis and moving the nation toward greater use of nuclear energy.

Selected R&D projects include thirty-one U.S. universities that will act as lead research institutions for projects in more than twenty states. Other universities, industries, and national laboratories will serve as collaborators and research partners. Under the Nuclear Energy University Program, DOE will support projects in the following nuclear energy research fields: the Advanced Fuel Cycle Initiative (AFCI), the Next Generation Nuclear Plant (NGNP) also known as Generation IV Nuclear Energy Systems, Investigator-Initiated Research (IIR), and Light Water Reactor Sustainability (LWRS).

The DOE also announced that it is accepting applications for individual nuclear science and engineering scholarships and fellowships under the Nuclear Energy University Program. As part of the Department's efforts to recruit and train the next generation of nuclear scientists and engineers, DOE is offering approximately $2.9 million in university fellowships and scholarships to support students entering the nuclear science and engineering fields. Further details on the Request for Applications are available at: http://www.caesenergy.org.

Contracts for the R&D projects are expected to be awarded by September 30, 2009, by the Battelle Energy Alliance, LLC (BEA), a Management and Operating contractor for DOE at the Idaho National Laboratory (INL).

U.S. and Colombia Commission Radiation Detection Operations at the Port of Cartagena

In March, the U.S. National Nuclear Security Administration (NNSA) participated in a commissioning ceremony at the Port of Cartagena in Colombia to highlight the successful operation of radiation detection equipment provided through NNSA's Megaports Initiative. This specialized system detects the presence of dangerous nuclear and other radioactive materials by scanning all import and export container traffic transiting the Port of Cartagena.

NNSA signed a joint Declaration of Principles with the Colombian Directorate of Customs and Taxation (DIAN) and U.S. Customs and Border Protection (CBP) in December 2006. This Declaration provided for the implementation of both the CBP's Container Security Initiative (CSI) and NNSA's Second Line of Defense Megaports Initiative. In September 2008, the Megaports radiation detection system at the Port of Cartagena became operational. DIAN is now staffing the central alarm station and analyzing and responding to radiation alarms, working closely with the port operator Sociedad Portuaria Regional de Cartagena (SPRC) to place automatic holds on suspect containers for further inspection.

Under a cost-sharing arrangement, SPRC paid for all design, construction, and installation efforts, while NNSA provided the equipment, communications system, training, technical support, and maintenance. The Megaports Initiative enjoys positive and productive relationships with all parties, but specifically recognizes SPRC for the significant financial investment in and commitment to preventing nuclear smuggling and for completing the project on time.

The Megaports Initiative is part of NNSA's Second Line of Defense Program, which aims to strengthen the capability of foreign governments to deter, detect, and interdict illicit trafficking in nuclear and other radioactive materials across international borders and through the global maritime shipping system. The Megaports Initiative provides radiation detection equipment, training, and technical support to key international seaports to scan cargo containers for nuclear and other radioactive materials.

Around the world, the Megaports Initiative is currently operational in twenty-one ports and work is underway at more than twenty additional ports in Asia, Latin America and the Caribbean, Europe, the Middle East, and Africa.

U.S. and Kenya Agree to Install Radiation Detection Equipment at the Port of Mombasa

The U.S. National Nuclear Security Administration (NNSA) has signed an agreement to work with the Ministry of Finance of the Republic of Kenya and other Kenyan agencies to install radiation detection equipment and associated infrastructure at the Port of Mombasa. NNSA will also train Kenyan government officials to use this equipment.

The Port of Mombasa links the trade corridors of the Indian Ocean, Red Sea, and Persian Gulf, and its strategic location makes it the maritime hub for countries throughout eastern and central Africa. Work at the Port of Mombasa will be performed under the Megaports Initiative, a key component of NNSA's Second Line of Defense (SLD) Program, which seeks to strengthen the capability of foreign governments to deter, detect, and interdict illicit trafficking in nuclear and other radioactive materials across international borders and through the global maritime shipping system. The Megaports Initiative provides radiation detection equipment, training, and technical support to key foreign seaports to enable them to scan cargo containers for nuclear and other radioactive materials.

New Zealand Increases Support to NNSA Effort to Prevent Nuclear Terrorism

The U.S. National Nuclear Security Administration (NNSA) will expand the ongoing partnership with New Zealand to help prevent nuclear terrorism around the world. Under an agreement signed with NNSA's Second Line of Defense (SLD) program, New Zealand will provide $350,000 (US) for nuclear nonproliferation work in Kazakhstan. The agreement was signed by Secretary of State Hillary Clinton during her meeting with New Zealand's Foreign Minister Murray McCully.

This is the second contribution from the government of New Zealand to SLD's work in the former Soviet Union. New Zealand has also contributed to the Second Line of Defense project in Ukraine. The agreement also includes provisions for New Zealand to make future contributions to SLD and NNSA's Global Threat Reduction Initiative (GTRI) projects over the next six years.

International contributions, whether financial or in-kind, augment NNSA programs aimed at improving the capabilities of our international partners to detect, secure and dispose of dangerous nuclear and radiological material. To date, NNSA has received support from New Zealand, Canada, Finland, the Republic of Korea, the Netherlands, Norway, and the United Kingdom to pursue nonproliferation efforts around the world, including:

- More than $31 million to shut down the last remaining weapons-grade plutonium production reactors in Russia.
- Nearly $12 million to reduce and protect vulnerable nuclear and radiological materials located at civilian nuclear sites worldwide.
- More than $10 million to strengthen security at international land borders, seaports and airports that may be used as smuggling routes for nuclear or radiological materials.

NNSA's Global Threat Reduction Initiative works to reduce and protect vulnerable nuclear and radiological material located at civilian sites worldwide.

Author Submission Guidelines

The *Journal of Nuclear Materials Management* is the official journal of the Institute of Nuclear Materials Management. It is a peer-reviewed, multidisciplinary journal that publishes articles on new developments, innovations, and trends in safeguards and management of nuclear materials. Specific areas of interest include international safeguards, materials control and accountability, nonproliferation and arms control, packaging and transportation, physical protection, and waste management *JNMM* also publishes book reviews, letters to the editor, and editorials.

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The *Journal of Nuclear Materials Management* is an English-language publication. We encourage all authors to have their papers reviewed by editors or professional translators for proper English usage prior to submission.

Papers should be submitted as Word or ASCII text files only. Graphic elements must be sent in TIFF, JPEG or GIF formats as separate electronic files and must be readable in black and white.

Submissions may be made via e-mail to Managing Editor Patricia Sullivan at psullivan@inmm.org. Submissions may also be made via by regular mail. Include one hardcopy and a CD with all files. These submissions should be directed to:

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111 Deer Lake Road, Suite 100
Deerfield, IL 60015 USA

Papers are acknowledged upon receipt and are submitted promptly for review and evaluation. Generally, the author(s) is notified within ninety days of submission of the original paper whether the paper is accepted, rejected, or subject to revision.

Format: All papers must include:

- Author(s)' complete name, telephone and fax numbers, and e-mail address
- Name and address of the organization where the work was performed
- Abstract
- Camera-ready tables, figures, and photographs in TIFF, JPEG, or GIF formats. Black and white only.
- Numbered references in the following format:
  1. Jones, F. T. and L. K. Chang. 1980. Article Title. *Journal* 47(No. 2): 112–118.
  2. Jones, F. T. 1976. *Title of Book*, New York: McMillan Publishing.
- Author(s) biography

Peer Review: Each paper is reviewed by at least one associate editor and by two or more reviewers. Papers are evaluated according to their relevance and significance to nuclear materials safeguards, degree to which they advance knowledge, quality of presentation, soundness of methodology, and appropriateness of conclusions.

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Vincent J. DeVito, Sr.
1923–2009

INMM Secretary VINCENT JOHN DEVITO Sr. died suddenly while playing golf in Naples, Florida, on April 8, 2009. Anyone who knew "Big Vince," as his family affectionately called him, knows that he played golf with the same passion that he lived life, and he could not have found a better way to depart us.

Vince was a special INMM member. His active participation in the Institute for nearly fifty years made him a legend. His talents of competency, wisdom, humor, intensity, thoroughness, memory, and passion will be sorely missed. With his passing, a special INMM era has come to a close.

Vince and Charles Pietri at the 2008 INMM Annual Meeting.

Vince became a member of INMM in 1960 and held the position of Secretary from 1973 until his passing. He has also served as the Public Relations Chair and on various ad hoc committees. Vince received the INMM Distinguished Service award in 1984 and was made a Fellow of the Institute in 1987. He received the Special Services award in 1997 and the Meritorious Service award in 2000 for his tireless and essential service to the Institute as secretary. Vince was more than our INMM Secretary. He was the unofficial historian of the Institute, and a recognized preeminent advisor.

Vince's View: A view from Vince DeVito's chair at the July 2008 Executive Committee Meeting.

Vince was a behind-the scenes mentor for most, if not all, new INMM presidents. Newly elected vice presidents made certain that he would continue as Secretary during their terms.

He was an active supporter of INMM initiatives, such as strategic planning and implementation, building student membership and activities, new INMM chapters, and the World Institute of Nuclear Security (WINS).

One of his favorite roles for INMM was that of chair of the Annual Golf Outing at the INMM Annual Meeting, which he did for many years. He also served as the unofficial historian for INMM. His long membership and his years of active involvement in the Institute made him a fount of information on all INMM activities.

Vince was an invaluable member of the INMM Awards Oversight Committee. His vast memory was always able to provide other committee members, not blessed with this attribute, valuable information concerning the history of the nominee's talents, career achievements, and human interest reminiscences. This, of course, benefited the committee members as well as the nominees. Vince was also an excellent "editor" of the various written procedures, commendations, Resolutions of Respect and all other texts produced by the Awards Oversight Committee. He could always find a more efficient or clearer way to express any

A special fund in Vince's memory has been established at the non-profit Stoneybrooke Foundation, an organization that serves people with Prader Willi Syndrome (PWS) a condition afflicting Vince's granddaughter, Nikah.

Send your donations to:
Stoneybrooke Foundation
303 E. Historic
Columbia River Hwy.
Troutdale, OR 97060

Contact:
Donna Stoney (503) 669-7191.
www.stoneybrookeresidential.com

Vince's family has set up a memorial Web site where his friends and colleagues are welcome to write comments: http://vincentdevito.blogspot.com/.

Vince DeVito with his wife Jeanne. The couple was married for fifty-five years until Mrs. DeVito's passing.

given thought. He was also superb at correcting grammar, spelling or other types of errors. And most of all, he could critique in such a way as to inform or improve without offending the authors.

Vince's sense of humor was infectious. Just to hear him laugh could lift the spirits of even the most stressed or harried person. For example, just having breakfast with Vince the morning after the conclusion of the Annual Meeting could wipe away all but the most joyous and satisfying memories for the hardworking and near exhausted Executive Committee members, committee chairs, and myriad other volunteers and staff who make the INMM meeting the success it always is. He was all business when the situation demanded it, but all pleasure when appropriate for the situation—qualities that led to his success as a businessman, a family man, and a citizen.

Vince was born in Canton, Ohio, on April 11, 1923, to Caroline and Angelo DeVito, and he was proud of his Italian heritage. As a young man he was active in the Drum & Bugle Corps. He was an exceptional student, skipped two grades in school, and graduated from high school during the Great Depression. With few work opportunities, he enlisted in the army only months before the U.S. entered World War II. During his five years as an airplane mechanic in the Army Air Corps, he spent time in England before traveling overland from Morocco to China where he served until the war ended. Returning to Ohio after the war, he married a war widow, Jeanne Phister. Smitten by her two young children, he raised them as his own, and the couple went on to have five more children.


INMM Member-at-Large Glenda Ackerman, Fellows Committee Chair Obie Amacker, Vince, INMM President Steve Ortiz, and (seated) Technical Program Chair Charles Pietri in the INMM Lounge celebrating 50th Anniversary of INMM during the 49th INMM Annual Meeting in Nashville, Tenn. USA, in July 2008. Vince had been a member of INMM since 1960.

In 1949 Vince earned a B.S. in Business from the Ohio State University and he remained an avid Buckeye throughout his life. After graduation he began his career with Goodyear in Akron, Ohio. In 1953 he was transferred to the Goodyear Atomic plant in Piketon, Ohio. He was director of site operations and was responsible for the plant's production and maintenance divisions, as well as plant security, shift operations and emergency preparedness organizations. He also held positions as superintendent of nuclear materials control; manager, safeguards and security division; manager, production division; and vice president, business services. In 1989 he retired from Martin Marietta (formerly Goodyear). Vince became a safeguards consultant for DOE contractors in 1989 and continued as a consultant until his death.

In addition to his passion for his family, golf, and INMM, Vince enjoyed traveling, photography, cooking and art. In the 1950s he and his wife started the Lake White Little Theatre with a group of friends. He was active in St. Mary's Church in Waverly, Ohio, and St. Williams Church in Naples. He was a man who never met a stranger; he loved his friends and was well loved by all who knew him. He was a big man with a huge heart.

He was preceded in death by his brother, Dr. John DeVito, stepson, Jack Doyle, stepdaughter, Diane Doyle Howells, and his beloved wife Jeanne, to whom he was married fifty-five years. His loving family including children Gerald DeVito, Daniel DeVito, Vincent DeVito, Jr., Victoria DeVito and Angela DeVito, his sister, Florence Scridon and fourteen grandchildren, survive him.

A memorial mass was celebrated in Canton on Saturday, June 6, at St. Anthony Catholic Parish. Interment was in Calvary Cemetery. A memorial service was held in Waverly, Ohio on Sunday, June 7.

Calendar

November 15–19, 2009
2009 ANS Winter Meeting and Nuclear Technology Expo
Nuclear Power: Crafting Energy Solutions
Omni Shoreham Hotel
Washington, DC USA
Sponsor: American Nuclear Society
Web Site: www.ans.org

November 15–19, 2009
2009 Young Professionals Congress
Omni Shoreham Hotel
Washington, DC USA
Sponsors: Young Members Group of the American Nuclear Society and the North American Young Generation in Nuclear
Web Site: http://www.ans-ypc.org/

December 14–18, 2009
International Conference on Effective Nuclear Regulatory Systems: Further Enhancing the Global Nuclear Safety and Security Regime
Cape Town, South Africa
Organizer: International Atomic Energy Agency
Host: the Government of South Africa through the National Nuclear Regulator of South Africa
Web Site: http://www.iaea.org

July 11–15, 2010
51st INMM Annual Meeting
Marriott Waterfront Baltimore Hotel
Baltimore, MD USA
Sponsor: Institute of Nuclear Materials Management
Contact: INMM
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❏ Equipment Manufacturer ❏ Government or International Agency ❏ Research or Consulting
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Field(s)/Subject(s) of expertise ______________________________

Total number of years work experience in nuclear materials management field(s) ___________

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2. ______________________________

3. ______________________________

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❏ Regular $50

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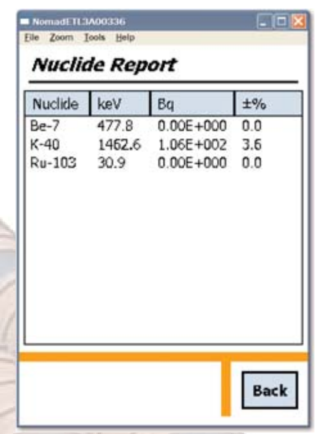

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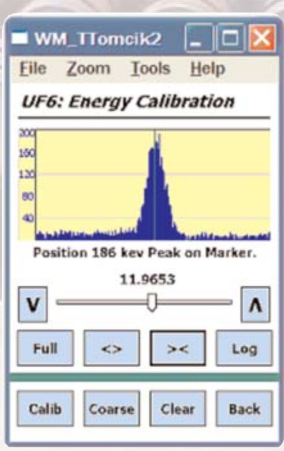

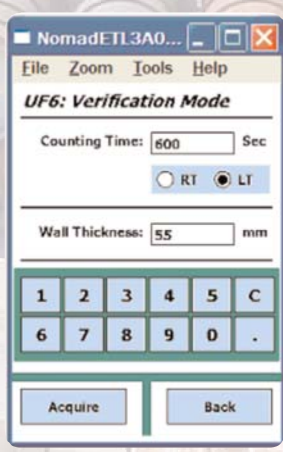

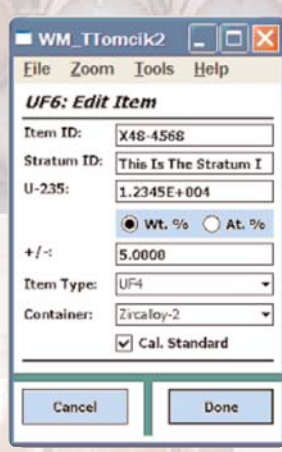

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