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50 Years of IAEA

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Brian McGowan
Advertising Director
Jill Hronek
INMM, 60 Revere Drive, Suite 500
Northbrook, IL 60062 U.S.A.
Phone: 847/480-9573; Fax: 847/480-9282
E-mail: jhronek@inmm.org

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INSTITUTE OF NUCLEAR MATERIALS MANAGEMENT

Challenges and Opportunities in Nuclear Materials Management

By Nancy Jo Nicholas
INMM President

As a professional society, INNM provides a global forum for our members and colleagues to explore and understand the new challenges to nuclear materials management in the changing global environment. This may be one of our most important roles because of the tremendous influence that INMM members have on the technical programs and policy debates in their home countries as well as in their many fields of expertise. INMM members help lead technical advances in nuclear materials management, provide sound, expert advice to policy makers, and disseminate best practices globally. The INMM continues to grow to meet these challenges. I am extremely pleased to announce that our third student INMM chapter recently was established at the University of Missouri.

Nuclear Energy Expansion

As the demand for energy and concerns about global warming grow, many are beginning to view nuclear power as the only viable, global-scale solution. Terms like nuclear energy renaissance and the global nuclear fuel cycle are now commonplace in coffee shops, university classrooms, and boardrooms alike. Expansion of the nuclear power industry in developed and developing nations is spurring expansion of nuclear engineering and research programs. Many of us have spent our careers addressing some of the challenges associated with nuclear energy: waste management and disposition; protection of reactors from terrorist attacks; safeguarding the full fuel cycle; and ensuring nonproliferation of nuclear weapon technologies. To succeed in our goals, we must not only address these challenges through the traditional means of policy and technology. In addition, we must work closely with the growing global nuclear power enterprise to ensure that safety, security and nonproliferation are integral to the design, construction and execution of the fuel cycle. Public awareness of the benefits and risks of nuclear power is high, and so are the opportunities for international funding and new collaborations. These are exciting times, and INMM members increasingly are on the forefront.

Fifty Years of IAEA

The subject of my column in the Winter 2006 issue of the *JNMM* was milestones. This special Summer edition of the *Journal* highlights fundamental contributions of the International Atomic Energy Agency to nuclear materials management over the last fifty years. I am proud of INMM's decades of partnership with the IAEA and look forward to future collaborations that will strengthen international safeguards and nuclear security. As you know, the IAEA was awarded the Nobel Peace Prize in 2005. This is an extraordinary achievement, and one in which everyone who works in the field of nonproliferation can take pride.

INMM 50th Anniversary Planning Update

Our Institute soon will reach a major milestone of its own. The INMM was founded on the May 17, 1958, and in October 1958 Dr. Ralph Lumb was elected the first chairman. To ensure that this milestone does not go unnoticed, we have formed an ad hoc committee under the leadership of Ed Johnson to plan a yearlong celebration of the INMM's 50th anniversary. This committee is planning a series of events to be held over a year-long period to commemorate INMM's 50th anniversary, culminating with the 50th Annual INMM Meeting in July 2009.

PATRAM 2007

The 15th International Symposium on Packaging and Transportation of Radioactive Materials (PATRAM 2007) will be hosted by the U.S. Department of Energy, Nuclear Regulatory Commission and Department of Transportation. INMM is proud to again co-host PATRAM, which will be held October 21-26, 2007, at the beautiful Marriott Doral Resort in Miami, Florida. This symposium will provide an excellent opportunity for nuclear materials management experts from government, industry and research organizations around the world to exchange information on all aspects of packaging and transportation of nuclear and radioactive materials. Ken Sorenson, chair of INNM's Packaging and Transportation Technical Division, has done a terrific job coordinating the PATRAM sponsorship and technical program. For program and registration information, visit the PATRAM Web site at www.patram.org online.

INMM President Nancy Jo Nicholas may be reached by e-mail at njnicholas@lanl.gov.

Celebrating Fifty Years of the International Atomic Energy Agency

By Dennis Mangan
Technical Editor

Again, as in several times in the past, we owe deep gratitude to our International Safeguards Technical Division, chaired by Jim Larrimore, who with the help of the division's Vice Chair Gottard Stein, formulated and solicited papers to recognize and celebrate the International Atomic Energy Agency's (IAEA) fiftieth anniversary. This issue, which by the way is the largest I can remember, is in my opinion a remarkable tribute to the IAEA and its efforts. In some respects, with two of my assignments at Sandia National Laboratories (SNL) being to manage SNL's international safeguards group and being a senior technical advisor to the United States' delegation negotiating the Trilateral Initiative involving the IAEA, the Russian Federation, and the United States, I feel as though I watched and maybe even helped in an indirect way the IAEA become a world class organization. As noted in one of the fine papers in this issue, "Well into the first decade of the twenty-first century, and a Nobel Peace Prize later, the IAEA has become, and needs to remain, a reference for the assessment of nuclear proliferation issues."

I believe the authors magnificently captured the IAEA's rich history and speculated on the possible issues of the future. For those of you not familiar with the IAEA who have a desire to learn about it, this issue has several articles that will provide keen insights. Each of the articles contributes something different, and all will agree with another statement in one of the articles, "Undoubtedly, the IAEA is the most important collective forum to ensure the safe and peaceful expansion of nuclear energy for the benefit of mankind."

The implementation of IAEA safeguards would not be possible without technology, and in particular technology that is specially designed to allow the IAEA to draw independent conclusions regarding a state's use of nuclear material. Several papers discuss the evolution of such technologies (where, I might add, acronyms appear to be a dime a dozen). As noted in one of the articles, "Safeguards, as any other security application, is an area in need of continuous R&D work. This is the only way to ensure proper protection with constantly changing threat scenarios."

As time marches on, there is the growing need for the agency to acquire and analyze more and more data. As note in one of the articles, "But perhaps nowhere else than in the area of international security has the need for extended data collection, advanced information evaluation and analysis, and proper dissemination of pertinent knowledge be more demanding, before the challenges identified at the end of the twentieth century."

This is indeed a very special issue of the *Journal* and our thanks go to all the contributing authors. It is one that is invaluably informing of IAEA's history, and it conveys the various states' attitudes in meeting its safeguard responsibilities while at the same time providing technical and political support to the agency. It's a credible birthday present for the agency, and the *Journal*, as well as the Executive Committee of the Institute and the Institute's membership congratulates the agency wishes it a very successful and rewarding future.

JNMM *Technical Editor Dennis Mangan may be reached by e-mail at dennismangan@comcast.net.*

Fifty Years of IAEA: Looking Back; Looking Forward

Introduction

Anniversaries are a time for celebration and for reflection. Fifty years—half a century—is a notable period of time. That is how long the International Atomic Energy Agency (IAEA) has been with us.

While much water has gone over the dam and many situations have arisen in these fifty years, the bases for safeguards established first in the IAEA Statute and then in INFCIRC/153 (1972) have held up remarkably well.

The INMM International Safeguards Technical Division (ISD) has periodically organized a special issue of the *Journal of Nuclear Materials Management,* and decided that honoring fifty years of IAEA was a good occasion for another special issue. We asked the authors to look back and to look forward.

We decided to invite views from colleagues around the world, and we are pleased to be able to present articles from Argentina and Brazil, Australia, Canada, Germany, Japan, Republic of Korea, South Africa, and the United States.

We also invited colleagues to prepare technical reviews on main aspects of international safeguards, and we present articles on formal models, NDA equipment, European R&D for safeguards, technologies for safeguards, and instrumentation for safeguards.

We are also pleased to have the IAEA represented. The head of the Department of Safeguards has kindly prepared a Foreword, and we have articles addressing legal perspectives and information management for safeguards.

The authors have done an excellent job in responding to the ISD invitation. We hope the readers will enjoy and learn from this special issue in recognition of the irreplaceable role of the IAEA in international safeguards over the past fifty years. May it continue for another fifty years!

Jim Larrimore, Chair, and Gotthard Stein, Vice Chair
INMM International Safeguards Division

Foreword

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

Anniversaries provide a focus for commemoration, reflection, and anticipation. The fiftieth anniversary of the founding of the International Atomic Energy Agency (IAEA) is no exception. I should therefore like to preface this special edition of the *Journal of Nuclear Materials Management* with some personal observations, which I hope will set the scene for the dedicated articles that follow.

Although under stress, I believe that the global regime centered on the Treaty on the Nonproliferation of Nuclear Weapons (NPT) continues to offer an essential and established foundation for nuclear nonproliferation. It is a regime that has periodically challenged its participants, including the IAEA and its safeguards system, to respond to new realities. Despite some well-known setbacks, the accumulated history of our safeguards system bears witness to its ability to cater to differing security demands and to adapt to change. Its ongoing relevance will continue to depend on such features.

We have come a long way since the IAEA was originally envisaged as a center through which safeguarded nuclear trade would be conducted, and whose first safeguards provided "peaceful use" assurance to nuclear exporters. One major milestone was the introduction of comprehensive safeguards agreements pursuant to the NPT and to the Tlatelolco Treaty. Another was the discovery of a nuclear weapons development effort concealed within Iraq's declared nuclear program. Adding to the verification experience that we had acquired over more than three decades, we learned from our experience in Iraq, in the DPRK, and in South Africa. We learned that our ability to provide credible assurance of compliance with safeguards obligations depends on our ability, underpinned by and based on the requisite legal authority, to assess the completeness of a state's declarations. We learned that nuclear transparency—essential to effective verification—is largely a function of the extent to which a state cooperates with the IAEA on safeguards implementation and provides information and access. We were also reminded of the added value that cutting-edge technology brings to the verification process.

The safeguards system continues to be what it has always been—the embodiment of accumulated experience, lessons learned, and adjustment, both to technological change and to geopolitical realities. At this point in time, its centerpiece is the Model Additional Protocol, approved by the IAEA Board of Governors in 1997 to provide new tools—and the essential basis—for completeness assessments.

The link between completeness and credible assurance has resulted in ongoing, iterative information assessment at the level of a state "as a whole." The state evaluation process, including related analytical capability and technology, have all matured considerably since their inception. State-level integrated safeguards approaches have been designed for fourteen states and are currently being implemented for twelve of them. New safeguards approaches are being developed to respond to new demands and new and/or improved equipment, techniques, and technologies continue to provide an important basis for more effective and efficient safeguards We have made progress on three broad clusters of efficiency measures related, respectively, to verification activities in the field; to the optimal use of safeguards equipment and technology; and to administrative, managerial and procedural improvements. There are other landmarks and achievements—and much work remaining.

On a less positive note, the IAEA's authority to implement safeguards remains uneven and, until that situation is redressed, we cannot realize the full potential of the safeguards system. Although safeguards agreements are now in force for the majority of states party to the NPT, some thirty-one states have still not fulfilled their legal obligation to conclude a comprehensive safeguards agreement and more than 100 states have yet to bring an additional protocol into force. Progress towards nuclear disarmament—and thus towards devaluing the currency of nuclear weapons—is sluggish. The nonproliferation landscape has again changed dramatically since the IAEA Board of Governors approved the Model Additional Protocol in 1997. We have witnessed the emergence of terrorist threats from non-state actors, further undeclared nuclear programs and activities and the uncovering of covert nuclear trade networks dealing in sensitive nuclear technology and information. Add to that the practical effects of ever-increasing globalization, the renewed interest that many states are showing in nuclear power and the prospect of new types of facilities coming on stream, and it is little wonder that the safeguards system must continue to be a work in progress which both addresses the present and anticipates the future.

Looking to the future, we have identified a number of priorities. Top of the list is to continue to encourage states that have not yet done so to adhere to the key instruments of the safeguards system, thereby enabling the IAEA to implement its safeguards measures in the most effective and cost efficient way. We must intensify our efforts to help states to strengthen their state systems of accounting for and control of nuclear material (SSACs) and to work with them as partners. We must embark, as necessary, on further, critical examination of aspects of safeguards implementation policy and take further measures, building on efficiency gains, to optimize our human and financial resources.

A key priority will be to continue working with our member states to identify and develop appropriate advanced technologies for the detection of undeclared nuclear material, facilities and activities. Towards this end, we must also reinforce our efforts to optimise our equipment and technology development. There are a number of other imperatives: environmental sampling has more than proven its worth as an effective safeguards measure and we must expand our capacity to analyse samples. "Information-driven" safeguards depend on cutting edge information collection and analytical capability and we must strive to make further inroads in these areas. Of particular significance is to enhance our ability to analyse trade in nuclear fuel cycle related technology and, in the future, to identify any other types of supplementary, safeguards-relevant information that might contribute to increased nuclear transparency. We must also be prepared to address any impact on safeguards of the consideration now being given to placing sensitive nuclear operations under multinational control.

Even if the checklist is daunting, I remain optimistic. I am optimistic because our safeguards system has shown its ability to respond and adapt to changing times and circumstances. As we celebrate this fiftieth anniversary year, few would argue that the world in which we now live is not light years away from the world in which the IAEA was brought into being, "to accelerate and enlarge the contribution of atomic energy to peace, health, and prosperity throughout the world," and to "ensure, so far as it is able," that nuclear energy is not used for military purposes. I am nevertheless convinced that, with the support of the international community, the IAEA safeguards system will continue to rise to the challenges it faces and maintain and strengthen its role as an essential part of the nuclear nonproliferation regime and global security system.

Safeguards and Nonproliferation:
The First Half-Century from a Legal Perspective

Laura Rockwood
Section Head, Nonproliferation and Policy Making Organs, Office of Legal Affairs
International Atomic Energy Agency, Vienna, Austria

Abstract

This article provides a retrospective of the historical development of safeguards and nonproliferation in “the first half century,” ranging from its origins through the statute of the International Atomic Energy Agency to the Model Additional Protocol, and reflections on possible outlooks for the future.

Introduction

I’d like to invite you to come with me on a journey—a journey through space and time in the development of the legal framework of the nuclear nonproliferation regime, and its cornerstone: IAEA safeguards.

What gave rise to this regime? Why has it continued to develop?

In my view, the nuclear nonproliferation regime came about as a function of states’ national and collective security needs, and has evolved as a function of their shifting perceptions of the risks to that security. Changes in those perceptions have produced changes in national security policy and, as a consequence, in nuclear nonproliferation policy and the legal framework for that policy.

Along our journey, we will see not only that the law and policies comprising the nonproliferation regime have changed, but that the rate of change has increased exponentially due to fundamental and rapid shifts in the perceptions of the risks.

To demonstrate these changes, and the acceleration in the rate of change, we will look at successive periods: the first twenty-five years, the following twenty years, the next decade, and the recent past, and then turn to speculations about the future of the nonproliferation regime.

The First Twenty Five Years: 1945–1970

Perceived risk: *Proliferation through the misuse of transferred items*
Response: *Create international verification body; develop system for verifying the use of supplied facilities, equipment, and material*

The dawning of the nuclear era—and the birth of the nuclear nonproliferation regime—was heralded by the most dreadful brilliance: the flash from the explosions of the first—and hopefully the only—nuclear weapons ever used against human beings.

While it was clear, even at the outset, that the atom could be exploited for the benefit of mankind, it was equally clear that the wielding of this mighty double-edged sword required restraint and control.

The first efforts to prevent the spread of nuclear weapons were based on the denial of technology, the assumption being that if the technology holders did not share their knowledge, its proliferation would be at least hindered.

In January 1946, the United Nations established a “commission … to deal with the problems raised by the discovery of atomic energy.” This commission, the United Nations Atomic Energy Commission (the “UNAEC,” consisting of the members of the Security Council and Canada), was tasked with developing proposals for the elimination of atomic weapons and for the control of atomic energy “to the extent necessary to ensure its use only for peaceful purposes.”

In June of that year, in an address to his “fellow members of the [UNAEC] and [his] fellow citizens of the world,” Bernard Baruch tabled a U.S. proposal for a mechanism designed to ensure that there would be no other nuclear weapons. The Baruch Plan was to create a supranational organization that would have a global monopoly in atomic energy, with the sole and exclusive right to conduct research in the field of atomic explosives. It would not just inspect, but own, control, and manage nuclear material and technology, and license and engage in nuclear activities, in exchange for which the United States gives up its nuclear weapons. It shortly became clear, however, that this proposition had been far too ambitious.

There was business to be had—plenty of demand for that new technology. But if there were to be trade in nuclear technology, there would be a risk that the supplied technology could be misused for the development of nuclear weapons unless there was some oversight. The solution to the problem as it was thus perceived? Restrained and controlled trade. So the technology holders began to sell nuclear material and small research reactors to other countries, pursuant to bilateral supply agreements, many of which invested the supplier with rights to verify that the supplied items would not be used for proscribed (military) uses.

However, clearly neither efforts to ban nuclear weapons, nor bilateral controls on nuclear trade, were going to work to stem the tide of nuclear weapons proliferation: the Soviet Union and the United Kingdom had already developed nuclear weapon programs and other states were working on their own nuclear programs (such as Belgium, Canada, France, and Italy).

Bilateral agreements were not sufficient to provide assurances to the broader community. To fully address the perceived risk, what was needed was not just bilateral pledges that supplied equipment would not be misused, but internationally binding nonproliferation undertakings by states, verified by an independent international entity.

At the 1953 United Nations General Assembly, U.S. President Dwight D. Eisenhower introduced his Atoms for Peace proposal: to create an international organization that could serve as a repository for nuclear material from the nuclear weapons states from which the non-nuclear weapon states could make withdrawals for peaceful purposes.[1] The new organization would be responsible for promoting safe and peaceful uses of nuclear energy, and would be entrusted with verifying that nuclear technology was not misused.

This organization was to become the IAEA: an intergovernmental organization, independent from the United Nations, but with a unique relationship permitting direct access to the United Nations Security Council.[2]

The statute of the IAEA was approved on October 23, 1956, by the Conference on the Statute of the IAEA, held at the United Nations in New York, and opened for signature three days later. It entered into force on July 29, 1957, following the deposit of instruments of ratification by eighteen states (among which, by operation of Article XXI of the statute, were required to be Canada, France, the Soviet Union, the United Kingdom and the United States) with the depositary government, the United States.[3]

While the original concept of the IAEA as a "nuclear broker" would not gain as much traction as originally foreseen, one very important function of the IAEA that would was its role in safeguarding the peaceful use of nuclear energy.

Article III.A.5 of the IAEA statute authorized the agency:

- To establish and administer safeguards to ensure that nuclear material, services, equipment, facilities, and information made available by the agency are not used to further any military purpose.
- To apply safeguards, at the request of the parties, to any bilateral or multilateral arrangement.
- To apply safeguards at the request of a state to any of that state's nuclear activities.

It is extraordinary that, during the height of the Cold War, consensus could be achieved on such a visionary role for a supranational inspectorate, and a safeguards system that anticipated measures that were novel and far-reaching, especially for its time: extremely broad rights of access at all times to all places and data and to any person who dealt with items required to be safeguarded; examination and approval by the agency of the design of specialized equipment and facilities to ensure that they would not further any military purpose, that they complied with applicable health and safety standards, and that they would permit effective application of safeguards; reporting and record-keeping by the state; and the possibility of reporting noncompliance to the Security Council.[4]

In 1961, the agency established the first "safeguards system," published in IAEA document INFCIRC/26, which covered only small research reactors, the technology that was being traded at that time. The system was extended in 1964 to cover large reactors (INFCIRC/26/Add.1). In 1964 and 1965, the agency's system was thoroughly revised (INFCIRC/66), and included procedures for safeguarding principal nuclear facilities[5] and nuclear material at other locations. In 1966 and 1968, the agency's safeguards system underwent further revision: first to add special provisions for safeguards at reprocessing plants (INFCIRC/66/Rev.1), and then to include additional provisions for safeguarded nuclear material in conversion and fuel fabrication plants (INFCIRC/66/Rev.2, the "Safeguards Document"). The Safeguards Document was not a *model* agreement, and its provisions only acquired legally binding force when and to the extent they were incorporated into safeguards agreements.

However, since the statute was not crafted in such a way as to make safeguards mandatory by virtue of membership in the IAEA, the implementation of safeguards in a state required the consent of that state. For many years, this consent would be manifested in the form of a safeguards agreement with the IAEA.[6]

Safeguards agreements are treaties[7] that are concluded between the IAEA and a state or states (and, in some instances, regional organizations, such as EURATOM[8] and ABACC[9]). They are drafted by the IAEA Secretariat; negotiated with the other parties to the agreement; approved by the Board of Governors; and signed by the Director General and by the Head of State, Head of Government or Foreign Minister of the state party (or representatives with full powers to do so). Depending on the

state's domestic requirements, the agreement enters into force either upon signature or upon receipt by the agency of written notification that the state's requirements for entry into force have been met.

While sharing common safeguards procedures, these INFCIRC/66-type agreements frequently varied from one to another in form and content. However, the state's undertaking in these agreements—not to use the safeguarded items for any military purpose—tracked the language of Article III.A.5 of the statute.

In terms of scope, the INFCIRC/66-type safeguards agreements evolved to cover the ever-increasing circumstances where safeguards were required (in connection with agency projects for the supply of nuclear material and/or facilities) or requested (in connection with bilateral supply agreements). They also extended beyond nuclear material and facilities to include equipment, nonnuclear material and even a nonnuclear facility (a heavy-water production plant). But they remained limited in scope, requiring the application of safeguards only in connection with the items specified in the agreement (and nuclear material produced, processed or used in connection with those items); hence, the reference to them as "item specific agreements."

As this first part of our journey comes to a close, one can see how the perception of the risks had started to shift. It was becoming increasingly clear that, as a natural consequence of the growing interest in nuclear energy and other applications of nuclear research and development (including nuclear weapons), importing states were beginning to develop their own capacity to produce nuclear material (such as Belgium, Canada, France, and Italy).

The march toward the possession of nuclear weapons continued unabated. By 1964, two more countries had acquired nuclear weapons. Science being what it is, and people's ingenuity being what it is, neither denial of technology nor restraint in trade alone would work. Nor, clearly, was it enough to try to safeguard individual supply arrangements. What was needed now was legally binding commitments by states not to acquire or develop nuclear weapons, and a mechanism for verifying compliance with those commitments.

This shift fuelled the next major development in the nuclear nonproliferation regime—a development marked by a series of landmark multilateral treaties.

In 1967, the Tlatelolco Treaty was to become the first of these: a treaty prohibiting nuclear weapons within a populated region (Latin America). A year later, the treaty establishing the European Atomic Energy Community (EURATOM), entered into force.[10]

In 1968, some seven years after the unanimous adoption by the United Nations General Assembly of an Irish draft resolution on the "prevention of the wider dissemination of nuclear weapons,"[11] and three years of labored negotiations in the Eighteen Nation Committee on Disarmament (ENDC), the text of the Treaty on the Nonproliferation of Nuclear Weapons (NPT) was commended by the General Assembly[12] and opened for signature.

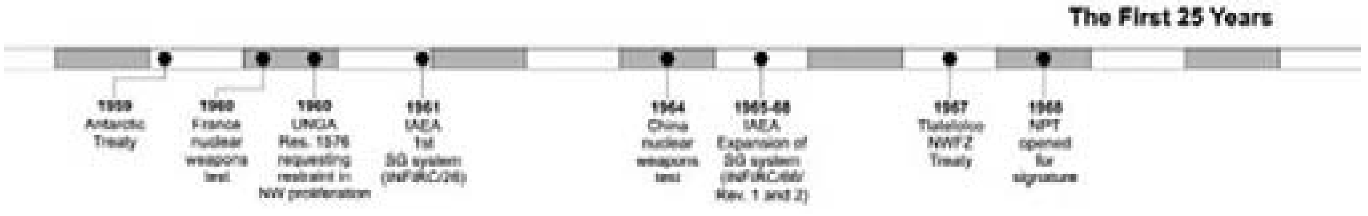
The Following Two Decades: 1970–1990

Perceived risk: *Proliferation through misuse of indigenous NNWS nuclear fuel cycle*
Response: *Develop a safeguards system for verifying inventories and flows of nuclear material in a state; develop export controls for nuclear material and specialized equipment and material*

If the first twenty-five years can be characterized as a period of controlled supply of nuclear material and nuclear facilities, the next two decades can be characterized as a period of ever-increasing indigenous development of nuclear fuel cycle activities.

On March 5, 1970, the world community brought into force the NPT,[13] the first treaty to include not only a prohibition against the *horizontal* spread of nuclear weapons by countries which had already exploded a nuclear device,[14] and a commitment by those who had not yet done so not to develop or acquire nuclear weapons, but a commitment by all parties to the cessation of the nuclear arms race and to disarmament.[15]

The basic premise of the NPT, insofar as the verification aspects were concerned, was that, without nuclear material, a state could not produce a nuclear weapon. Therefore, if all imports and domestic production of such material were subject to safeguards, the nonproliferation of nuclear weapons could be assured. Thus, Article III.1 of the NPT obliged each non-nuclear-weapon state (NNWS) party to the treaty to "accept safeguards, as set forth in an agreement to be negotiated and concluded with the [IAEA], in accordance with the statute of the [IAEA] and the agency's safe-



guards system, for the exclusive purpose of verification of the fulfilment by [the state] of its obligations under [the NPT] with a view to preventing diversion of nuclear energy from peaceful uses to *nuclear weapons or other nuclear explosive devices"* (emphasis added).

Under the NPT, safeguards were to "be followed with respect to source or special fissionable material whether it is being produced, processed, or used in any principal nuclear facility or is outside any such facility" and be applied on "*all* source and 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).

The IAEA's Board of Governors established a Safeguards Committee (Committee 22) to advise it on the contents of these new agreements. Over a period of two years, the committee developed a document entitled "Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Nonproliferation of Nuclear Weapons," which was approved by the Board of Governors in 1972 and published as INFCIRC/153 (Corr.)—the original "blue book."

While not a model agreement per se, INFCIRC/153 spelled out in great detail what such an agreement was to include. As a result, unlike agreements concluded on the basis of INFCIRC/66, these agreements were to be highly standardized. These new agreements clearly needed to differ from the earlier not only in form, but in undertaking and scope.

In terms of scope, since the purpose was to cover all nuclear material of a state, rather than only items which the state(s) concerned chose to submit to safeguards, these new agreements would become known as *full scope or comprehensive* safeguards agreements (CSAs).

In anticipation of the possibility of non-proscribed military nuclear activities (in particular, nuclear naval propulsion), the basic undertaking of NNWSs under the NPT prohibited the use of nuclear energy for nuclear weapons and nuclear explosive devices. Thus, unlike the earlier safeguards agreements, the NPT agreements would not prohibit all military uses of nuclear material.

Some years later, in 1982, in response to questions raised during a meeting of the Board of Governors, the Secretariat was asked to prepare a study on the compatibility between the undertaking in the NPT safeguards agreements and "the statutory legitimacy of non-explosive military applications of nuclear material subject to the agency's safeguards system" and to inform the Board. In IAEA document GOV/INF/433 (January 21, 1983), the Secretariat submitted the results of its study, in which it concluded that, based on the negotiation history of the statute, and subsequent practice of the Board as the organ which had authority under the statute to determine the safeguards functions of the agency and to approve all safeguards agreements, Article III.A.5 did not require that the undertaking in all safeguards agreements preclude military non-explosive military applications.

The nuclear-weapon states (NWSs) party to the NPT subsequently also concluded safeguards agreements based on INFCIRC/153, pursuant to voluntary offers to place certain nuclear activities under safeguards.[16] These so-called voluntary offer agreements (or VOAs) resembled the CSAs, but the scope of these agreements was limited, covering only those facilities and material which the state chose to offer to the IAEA.

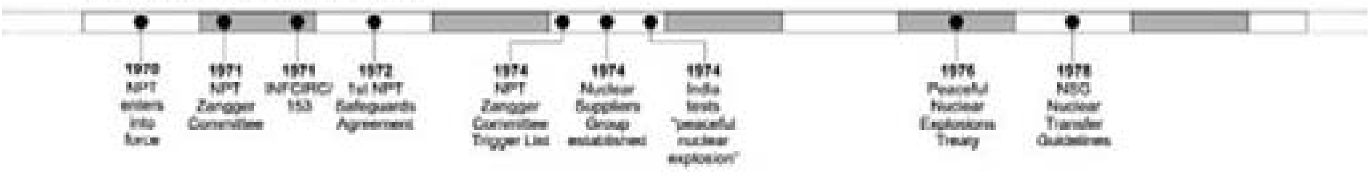
One of the provisions in INFCIRC/153 calls for the suspension of the application of safeguards under other safeguards agreements concluded by the state (i.e., the earlier INFCIRC/66-type agreements).[17] In time, the application of agency safeguards under most of the item-specific agreements would be suspended in favour of NPT safeguards agreements (today, INFCIRC/66-type agreements are implemented only in India, Israel, and Pakistan). But not before another event occurred, which had a significant impact on the development of safeguards: India's "peaceful nuclear explosion."

The detonation of India's nuclear device brought about another paradigm shift in the perception of the risk. Clearly, nuclear technology transferred for peaceful purposes could be misused.

This resulted in a revision by the IAEA of a state's basic undertaking in safeguards agreements concluded on the basis of INFCIRC/66. No longer would the proscription be simply against military uses of safeguarded items. The undertaking would thereafter also expressly preclude the use of such items for any nuclear explosive device.

Among the *fallout* from India's test was the strengthening of export controls.

In the early 1970s, nuclear technology had been sufficiently limited that most states were unable to develop nuclear fuel cycles



without some external assistance from technology holders in the form of equipment and materials that were especially designed or prepared for nuclear use. To address concerns about the possible misuse of such equipment and material, the drafters of the NPT included in Article III.2 an obligation on the part of all states parties not to provide: "(a) source or special fissionable material, or (b) equipment or material especially designed or prepared for the processing, use or production of special fissionable material, to a non-nuclear-weapon state for peaceful purposes, unless the source or special fissionable material shall be subject to the safeguards required by this Article."

While the Board of Governors was engaged in the negotiation of what was to become INFCIRC/153, a group of major nuclear suppliers regularly involved in nuclear trade—the Zangger Committee—convened with a view to reaching common understandings on how to implement Article III.2 of the NPT. In 1974, the Zangger Committee asked the IAEA to publish its so-called "trigger list" of "equipment or material especially designed or prepared for [EDP] the processing, use, or production of special fissionable material," the export of which to NNWSs would *trigger* a requirement for safeguards. In addition to the NPT requirement of safeguards on such transfers, the Zangger Committee also agreed that the supply of "EDP items" should be contingent upon a non-explosive-use assurance by the recipient state and a commitment to insist on the same conditions when retransferring such items.[18]

Following India's nuclear test, the Nuclear Suppliers Group, a group consisting of the major nuclear supplier countries who were members of the NPT Zangger Committee and those that were not party to the NPT, was created with a view to improving the conditions of transfers of single use (i.e., nuclear material and other EDP) items for peaceful purposes to help ensure that nuclear cooperation would not be diverted to unsafeguarded nuclear fuel cycles or nuclear explosive activities. The NSG developed its own list of controlled items and agreed on guidelines for the transfer of such items. Among these was agreement on the exercise of particular caution in the transfer of sensitive technologies and materials (i.e., enrichment and reprocessing) because they could lead directly to the creation of material usable for nuclear weapons or other nuclear explosive devices.

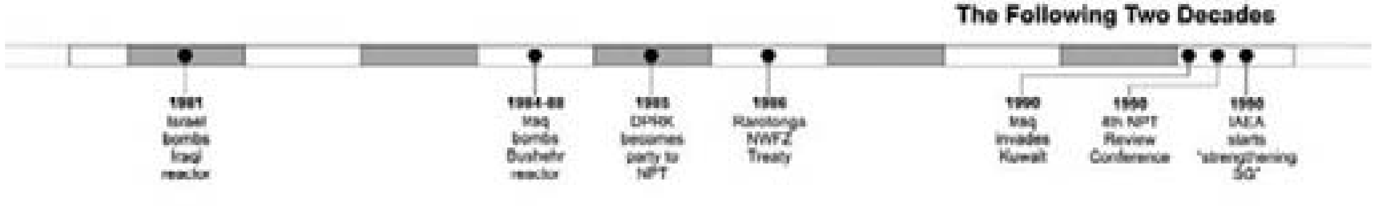
Despite the Indian nuclear explosion, the 1981 bombing by Israel of an Iraqi reactor and, a few years later, the bombing by Iraq of an Iranian reactor, the "nonproliferation mood" at the end of these two decades was pretty upbeat—the Cold War was ending, the Berlin Wall had been brought down, and the United States and the Soviet Union had made substantial progress in arms control and disarmament. As of the end of 1990, 141 states had become party to the NPT, including China and France, the two remaining nuclear-weapon states. And the IAEA had managed to develop a comprehensive safeguards system that permitted the verification of imports and domestic production of nuclear material.

But not all was well in the realm of nuclear nonproliferation. The regime, as it existed at the close of the 1990s, had limitations and drawbacks—as a matter of law and practice—the consequences of which were soon to reverberate throughout the world.

As a matter of law, while safeguards were now in place on the key choke points of the nuclear fuel cycle, the comprehensive safeguards agreements did not cover the entire nuclear fuel cycle. Routine access was limited in terms of frequency and location, and had to be agreed upon with the inspected state. The safeguards agreements included provisions permitting states to exclude nuclear material from safeguards (e.g., exemption, termination). States that informed the IAEA that they had little or no nuclear material and no nuclear material in a facility were allowed to conclude protocols that effectively precluded IAEA verification in those countries.

Most problematic of all, however, was the fact that the safeguards system had developed, as a matter of practice, into verifying only that which was declared to the agency. The combination of member states' frequently reiterated fear of the IAEA carrying out "fishing expeditions," and the Secretariat's cautiousness in pressing the boundaries of its legal authority, had resulted in the implementation of safeguards that were focussed on the verification of declared nuclear material (i.e., the correctness of states' declarations), and not the absence of undeclared nuclear material or activities in the state (i.e., completeness).

In addition, limitations persisted in the export controls of the nonproliferation regime. The Zangger Committee and the NSG (Nuclear Suppliers Group) both operated within the framework of informal, non-legally binding arrangements. And both the trigger list and the guidelines were limited both in scope (insofar as



they did not provide for control on dual use items) and in conditions (the safeguards required as a condition of supply were still only of the item-specific type, to be applied only to the supplied material, facility or other item). There were no procedures for exchanging information on export denials and no sharing of information with the IAEA).

Over the next decade, much of that would change.

The Next Decade: The 1990s

Perceived risk: *Proliferation through undeclared nuclear material and activities in NNWSs*
Response: *Ensure verification of non-diversion of declared nuclear material and absence of undeclared nuclear material and facilities; expand and improve export controls*

To be fair, the IAEA Secretariat and its member states had already begun to contemplate the need to strengthen IAEA safeguards in 1990. Although no final document was agreed at the 1990 NPT Review Conference in Geneva, the text reported out by Main Committee II (the Safeguards Committee) included language welcoming a study by the IAEA of the possible scope, application, and procedures for special inspections in NPT states where uncertainty existed about whether a state had declared to the IAEA all of the nuclear material required to be subject to safeguards. In addition, in his address to the General Conference in September 1990, immediately following that Review Conference, the Director General also raised the prospect of measures to improve the safeguards system, including the use of unannounced inspections. However, there still remained strong resistance to expanding the IAEA's verification role, whether by practice or by law.

As they say, there's nothing like a crisis to focus one's attention, however.

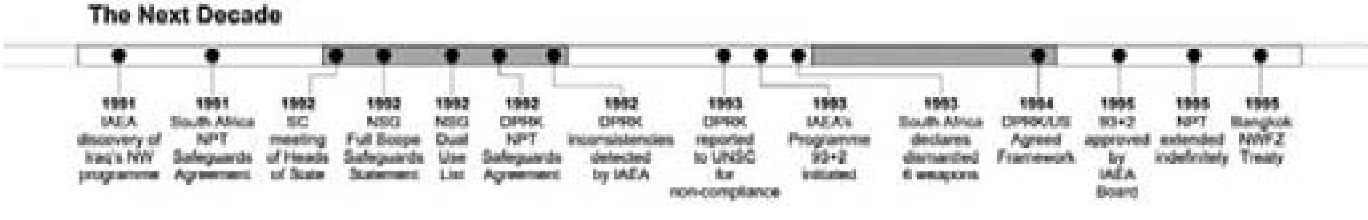
In April 1991, the IAEA uncovered undeclared nuclear material and activities in Iraq, much of which had been collocated on the site of three safeguarded nuclear facilities just a short ride from Baghdad. Operating under the authority of Chapter VII of the UN Charter, through intrusive inspections and access to all information, people, and locations it deemed necessary, the IAEA was able, by October 1997, to uncover, map out, and dismantle Iraq's program for the production of nuclear weapons. Iraq's clandestine program exposed all too clearly the limitations of a safeguards system focussed exclusively on declared nuclear material.

And that was just the overture for the decade. The years between 1991 and 2000 were characterized by dramatic challenges to the agency's safeguards system, fundamental shifts in states' perceptions of the risks to their individual and collective security, and, as a consequence, fundamental changes in the nonproliferation regime.

Member states of the IAEA, and the world community at large, questioned how it had been possible for Iraq to have developed an undeclared enrichment program, effectively "under the nose of the IAEA." The answer was as simple as it was unfortunate. It was not a question of the lack of legal authority; paragraph 2 of INFCIRC/153 already provided not only for the right, but the obligation, of the agency to ensure that "safeguards will be applied, in accordance with the terms of the Agreement, on *all* source or special fissionable material." However, over the years, the IAEA and its member states had somehow bought into the idea that the agency's authority was limited to verifying declared nuclear material, and that efforts to ensure that there was no undeclared nuclear material in the state would be rebuffed. Even had the agency been amenable to carrying out inspections to ensure the absence of undeclared nuclear material and activities, however, the Secretariat could not have done so without information, some indicator, giving rise to the need for such inspections, information that it was not able to acquire in the course of routine inspections and was not available from other sources.

It was time for another quantum shift in perception of the risk. The world community had already developed solutions to address the risk to peace and security posed by the possible misuse of supplied nuclear material and technology, and other solutions to address the risk of misuse of declared indigenous nuclear fuel cycles. It was time now to address the clear and present danger attributable to a newly perceived risk: that of a state concealing nuclear material and activities in contravention of its international obligations.

In the same year that Iraq's nuclear weapons program was uncovered, South Africa, a long-time NPT "hold out," became party to the NPT and concluded a comprehensive safeguards agreement. If Iraq had raised member states' awareness of the risk posed by undeclared nuclear material and activities, South Africa



provided them with another, somewhat different, but equally clear, case in point. In September 1991, the General Conference of the IAEA adopted a resolution requesting the Secretariat to verify the correctness and completeness of South Africa's initial declaration of nuclear material which, with the openness and transparency on the part of the South African Government, the agency was able to do.[19]

On January 31, 1992, the Security Council, meeting at the level of heads of state and government, issued a presidential statement (S/23500) in which the Council, *inter alia,* stated that the proliferation of all weapons of mass destruction constituted a threat to international peace and security and, with respect to nuclear nonproliferation, noted "the importance of the decision of many countries to adhere to the [NPT] and to emphasize the integral role in the implementation of that Treaty of fully effective IAEA safeguards, as well as the importance of effective export controls." The Council continued, stating that the members of the Council would "take appropriate measures in the case of violations notified to them by the IAEA."

The safeguards agreement with the Democratic People's Republic of Korea (DPRK) entered into force later that same year. Putting its recently acquired experience to use, the IAEA was able to take advantage of the new tools and practices it had developed in Iraq and South Africa (in particular environmental sampling) to detect inconsistencies in the DPRK's initial declaration about its nuclear material. These inconsistencies gave rise to serious concerns about the possible presence in North Korea of plutonium that had not been declared to the IAEA. The IAEA was also able to make use of intelligence imagery to identify locations not declared to the IAEA, access to which the agency believed would assist it in resolving those inconsistencies.

If, as lawyers are prone to saying, hard cases make bad law, an easy case makes good law. The compelling presentation put by the Secretariat to the Board of Governors, meeting in closed session in February 1993, convinced the Board not only of the need for access to additional information and the undeclared locations, but the agency's right to request such access under the provisions for special inspections.[20] Unfortunately, the DPRK denied the agency's request. This was reported to the Board of Governors, which, in turn, decided to report the DPRK's non-compliance to the Security Council in April 1993.

This sequence of events clearly put to rest any doubts about the agency's right and obligation under comprehensive safeguards agreements to verify the absence of undeclared nuclear material and activities, and its right to request access to undeclared locations. The objective of safeguards had been redefined in response to states' shifting concerns. These events also gave rise to additional changes in export controls.

In response to the discovery of Iraq's nuclear weapons program, much of which had been developed through the acquisition of dual-use items not covered by the NSG Guidelines, the NSG agreed in 1992: on guidelines for transfers of dual-use equipment, material and technology; on a framework for consultations and exchange of information on the implementation of the guidelines; on procedures for exchanging notifications of denials; and on the need to make full-scope safeguards a condition for the future supply of trigger list items to any NNWS.

Between 1991 and 1995, the IAEA identified a number of measures to "fill the gaps" in the implementation of agency safeguards. Its first efforts were focused on ensuring the early provision of design information on new facilities and modifications to existing facilities, and the voluntary provision of information on exports and imports. In June 1993, responding to the Director General's report of recommendations by the agency's Standing Advisory Group on Safeguards Implementation (SAGSI) for strengthening the effectiveness and efficiency of IAEA safeguards, the Board of Governors requested the Director General to submit to the Board in December 1993 concrete proposals for the assessment, development and testing of measures proposed by SAGSI. These efforts were formalized into "Program 93+2," a coordinated and intensive Secretariat effort, approved by the Board in December 1993 and carried out in continuous consultation with member states. As the name of the program suggests, it was clearly expected that concrete results would be produced in time for the critical 1995 NPT Review and Extension Conference.

By March 1995, the Board had approved the Director General's decision to implement those measures determined to be within the existing authority available to the agency under INFCIRC/153, and had determined that complementary legal authority should be developed to provide the agency with the broader access to information and locations necessary for the agency to improve the effectiveness and efficiency of safeguards.

The Board also reconfirmed that "… the safeguards system for implementing [comprehensive safeguards agreements] should be designed to provide for verification by the agency of the correctness and completeness of states' declarations, so that there is credible assurance of the non-diversion of nuclear material from declared activities and of the absence of undeclared activities."

The spring of 1995 brought about a critical turning point in the nonproliferation regime: the indefinite extension of the NPT by decision of the states parties at the 1995 NPT Review and Extension Conference. The Conference took two other key decisions, one on a strengthened review process for the Treaty and another on "Principles and Objectives for Nuclear Nonproliferation and Disarmament."[21]

The "Principles and Objectives" included a statement to the following effect:

> "The [IAEA] is the competent authority responsible to verify and assure, in accordance with the statute of the Agency and the Agency's safeguards system, compliance with its safeguards agreements with states parties undertaken in fulfilment of their obligations under article III (1) of the Treaty, with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices. Nothing should be done to undermine the authority of the IAEA in this regard. States parties that have concerns regarding non-compliance with the safeguards agreements of the Treaty by the states parties should direct such concerns, along with supporting evidence and information, to the IAEA to consider, investigate, draw conclusions and decide on necessary actions in accordance with its mandate."

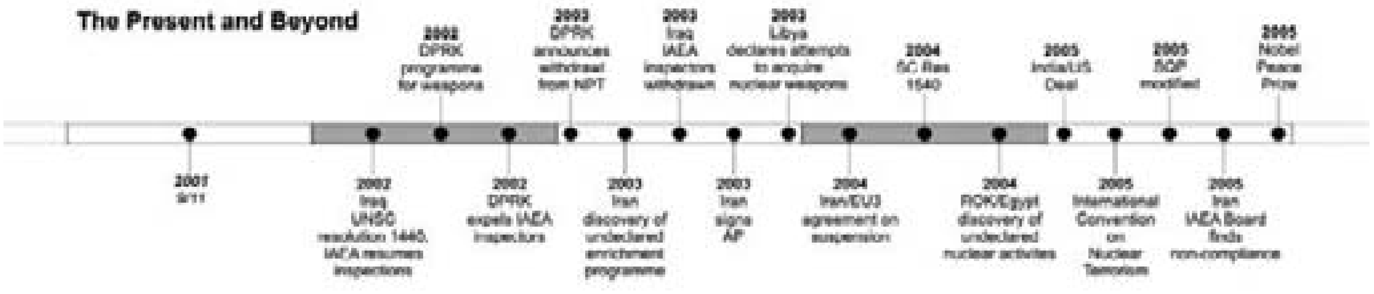
But the Principles and Objectives were not just about safeguards. They also contained passages on disarmament and security assurances, identifying among the relevant principles and objectives: reaffirmation by the nuclear-weapon states of their commitments in Article VI of the NPT; the importance of pursuing in good faith negotiations on effective measures relating to nuclear disarmament, achieving a universal and internationally verifiable Comprehensive Nuclear Test Ban Treaty (CTBT), negotiating a fissile material cut-off treaty (FMCT), and determined pursuit by the NWSs of systematic and progressive efforts to reduce nuclear weapons, with the ultimate goal of eliminating such weapons. These principles and objectives would come under renewed scrutiny and challenge ten years later.

Within two years, the committee established by the board to negotiate a model text for complementary legal authority completed its task. Based on a first draft prepared by the Secretariat, the committee agreed on a Model Additional Protocol to the Agreement(s) between State(s) and the IAEA for the Application of Safeguards, designed to provide the agency with new tools for achieving the objective of safeguards: verifying the correctness and completeness of states' declarations under comprehensive safeguards agreements. In a special session held in May 1997, the board approved the text, and requested the Director General to use it as the standard for additional protocols to be concluded in connection with comprehensive safeguards agreements. The board also requested the Director General to negotiate additional protocols with other states, incorporating those measures that those states were prepared to accept.

Rounding out this decade, the parties to the NPT convened the sixth quinquennial Review Conference in New York in April 2000. In its Final Document, the Conference reiterated the conviction of the states parties that the IAEA was the competent authority responsible for verifying compliance with NPT safeguards agreements; reaffirmed that IAEA safeguards should be regularly assessed and evaluated; stated that decisions aimed at strengthening safeguards should be supported and implemented; and endorsed the measures of the Model Additional Protocol. After a hard-fought battle, the Conference also agreed on thirteen steps for the systematic and progressive efforts to implement Article VI of the NPT, which included, *inter alia,* the early entry into force of the CTBT, the negotiation of an FMCT, and specific steps by all NWSs leading to nuclear disarmament in a way that would promote international stability, based on the principle of undiminished security for all.

In 1998, India and Pakistan both openly carried out much publicized nuclear weapons tests, which were roundly condemned by the agency's Board of Governors and General Conference, as well as the Security Council.[22]

Notwithstanding, by the end of the decade, the prospects offered by a strengthened safeguards system, improved export controls and renewed commitments by the nuclear-weapon states to the "principles and objectives," and in particular to disarma-



ment, made for an optimistic outlook for the nonproliferation regime and IAEA safeguards.

The next few years, however, would dramatically alter that outlook.

The Present and Beyond: Challenges of the New Millennium

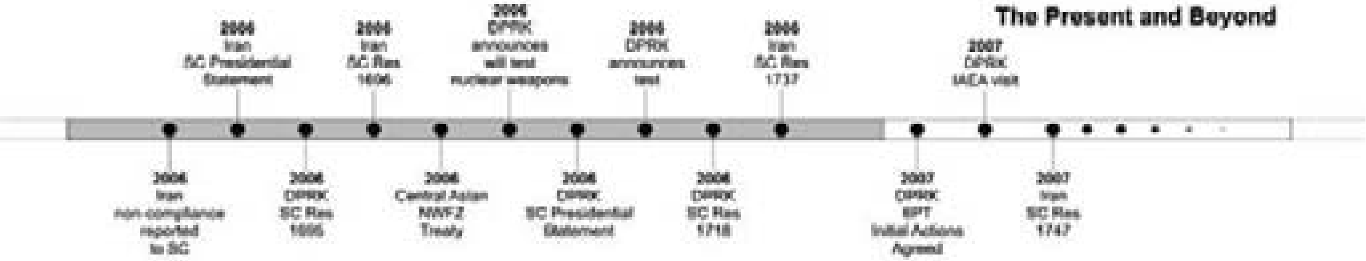
Where are we now? Where are we headed?

Iraq—After four years of absence from Iraq, agency inspectors were allowed back into Iraq in November 2002, only to be withdrawn four short months later, just before being able to finalize a report to the Security Council that would have conveyed the agency's conclusion that it had found no indications of the resumption of a nuclear weapons program in Iraq. It is notable, however, that the agency's preliminary findings to this effect were later validated—after almost two years and the expenditure of more than $1 billion U.S.—by the Duelfer Report. The agency has been able to carry out its yearly safeguards inspection of the nuclear material remaining at Tuwaitha, but is still awaiting review by the Security Council of the agency's mandate under the relevant Security Council resolutions.

DPRK—Since 1994, the IAEA had been limited to verifying compliance by the DPRK with the Agreed Framework concluded between the United States and the DPRK. However, following conflicting public reports in mid-2002 about declarations by the DPRK that it had a nuclear-weapons-related enrichment program, and charges by the DPRK that the United States had breached the Agreed Framework, the DPRK expelled the IAEA's inspectors in December of that year and, in early 2003, announced its withdrawal from the NPT. After an extended series of on-again, off-again diplomatic efforts under the so-called Six Party Talks, in September 2005, a Joint Statement on the Korean Peninsula Nuclear Issue was agreed between the DPRK, China, the United States, Japan, the Republic of Korea, and Russia, in which the Six Parties, inter alia, reaffirmed their common goal of the verifiable denuclearization of the Korean Peninsula in a peaceful manner and agreed to take coordinated steps to implement this goal in a phased manner in line with the principle of "commitment for commitment, action for action." In October 2006, the DPRK announced that it had conducted a nuclear weapons test. On February 13, 2007, the Six Parties announced agreement on initial actions for the implementation of the Joint Statement. Among the steps agreed to was that the DPRK would "shut down and seal for the purpose of eventual abandonment the Yongbyon nuclear facility, including the reprocessing facility and invite back IAEA personnel to conduct all necessary monitoring and verifications as agreed between IAEA and the DPRK." In early March 2007, the Director General, at the invitation of the DPRK, visited the DPRK, where he held exploratory discussions concerning the "initial actions." The DPRK indicated its willingness to invite the agency for further discussions once the issue of financial sanctions had been resolved.

Iran—In the first few months of 2003, the IAEA uncovered in Iran previously undeclared nuclear material and activities associated with conversion, uranium enrichment and reprocessing, much of which had been fueled by a clandestine international market in nuclear technology, equipment, and material. Some of the major events which took place in this context are indicated in the timeline below. In September 2005, the Board of Governors found Iran to be in non-compliance with its safeguards agreement, and, following Iran's announcement of its intention to resume its enrichment related activities, the Board in February 2006 requested the Director General to report the non-compliance to the Security Council. The Security Council has since then adopted a presidential statement, followed by two resolutions: one in December 2006, imposing sanctions on Iran for its non-compliance; and one in February 2007, expanding the sanctions. As of April 2007, the IAEA remained unable to verify the correctness and completeness of Iran's declarations.

Libya—At the end of 2003, Libya publicly announced that it had had a program intended for the production of nuclear weapons, and that it had been engaged for more than a decade in the development of a uranium enrichment capability, including the import of undeclared uranium and centrifuge and conversion equipment and the construction of pilot scale centrifuge facilities. Libya renounced this and its other weapons of mass destruction (WMD) programs, and permitted the IAEA to verify that, henceforth, all of its nuclear activities would be under safeguards and used for exclusively peaceful purposes. The stark awakening? Much of the information, equipment, and materials acquired by Libya for its clandestine nuclear program had been acquired from the same illicit nuclear trade network that had supplied Iran's enrichment program.



The good news? The IAEA's ability to verify the correctness and completeness of states' declarations has been substantially improved and, as a consequence, it was able to uncover instances of small quantities of undeclared nuclear material and activities in the Republic of Korea and Egypt, even though these activities did not rise to the level of those found in Iran or Libya.

NPT—The 2005 NPT Review Conference is described by almost all participants as having been a resounding and dismal failure, with tensions between and among state parties about the spread of sensitive nuclear technologies and those who challenged the lack of progress by the nuclear-weapon states in arms control and disarmament. As of the time of the April 2007 Preparatory Committee meeting in advance of the next Review Conference 2010, these conflicts persist, a situation that does not bode well for the future.

CTBT/FMCT—Ten years after its signature, the CTBT has not yet come into force, despite the fact that 170 countries have signed the Treaty and 135 countries have ratified it. And in the past ten years, it has not been possible even to agree on a mandate to start negotiating the FMCT.

Perceived Risks?

Clearly, the events of the last few years have produced, yet again, a shift in the perception of the risks to states' security:

- Illicit nuclear trade networks, and the involvement of non-state actors
- The *breakout* scenario—withdrawal from the NPT, preceded by the development of sensitive technologies and possibly weaponization activities
- Disarmament slowdown—resentment abounds due to the continuing perception that nuclear-weapon-states are not living up to their part of the NPT bargain by achieving progress in disarmament

Possible Responses?

Each of these risks could be mitigated through a three-tiered approach to possible solutions:

Strengthening the nonproliferation regime:

- Comprehensive safeguards agreements with an Additional Protocol should be established as the verification standard. As of April 2007, there were 190 states party to the NPT (if one includes the DPRK). Of these, thirty-one NNWSs party to the NPT had not yet concluded comprehensive safeguards agreements, and more than 100 states had yet to bring into force additional protocols.
- Export controls could be further improved, and made binding through international agreements
- More information concerning nuclear trade could be shared with the IAEA
- The regime should be shored up against the risk of non-state actors through effective implementation of Security Council Resolution 1540

Minimizing the risk of breakout:

- Internationalizing key points of the nuclear fuel cycle: A number of proposals for multilateral approaches to the nuclear fuel cycle, in particular as regards the sensitive technologies of enrichment and reprocessing, are currently circulating. In this vein, it is perhaps little appreciated by the international community today that the statute of the IAEA already authorizes the agency to receive nuclear material from member states, to supply such material to its member states, and to establish its own plants, equipment and facilities for the receipt, storage and issue of such material. [23]
- Ensuring Security Council response to threats of NPT withdrawal

Ensuring the survival of the nonproliferation regime:

- Accelerating disarmament by NWSs
- Addressing over-arching security concerns of NNWSs

Conclusion

If the initial premise of this paper is correct, that the nonproliferation regime, and IAEA safeguards, have evolved as a function of states' security needs, and states' perceptions of the risks thereto, one must look beyond the day-to-day efforts to fill gaps as they arise and try to resolve the basic issues underlying national and collective insecurity, for the more secure a nation and its people are, surely the less attractive is the appeal of nuclear weapons.

Laura Rockwood has served in the Office of Legal Affairs of the IAEA since 1985. She has been involved in all aspects of the negotiation, interpretation and implementation of IAEA safeguards agreements for twenty-two years, and was the principal author of the document that became the Model Additional Protocol. She has participated, inter alia, in: the Director General's Expert Group on Multilateral Approaches to the Nuclear Fuel Cycle; three NPT Review Conferences; and the trilateral negotiations between the IAEA, Russia, and the United States to develop an agreement on the verification of materials released from weapons programs. Rockwood is a regular lecturer at the International School of Nuclear Law in Montpellier, France, and the World Nuclear University Summer Institute. She received her bachelor of arts degree from the University of California, Berkeley, in 1973, and her juris doctor degree from the University of California's Hastings College of the Law in San Francisco in 1976. She is a member of the State Bar of California and the Washington, D.C. Bar Association. Prior to working for the IAEA, Rockwood was employed by the U.S. Department of Energy as a trial lawyer, principally in radiation injury cases, and as counsel in general legal matters.

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2. Fischer, D. 1997. *History of the International Atomic Energy Agency: The First Forty Years. Vienna:* IAEA.
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Notes

1. Bunn, G., 1992. Arms Control by Committee: Managing Negotiations with the Russians. Stanford: Stanford University Press.
2. IAEA Statute, Articles III.B.4 and XII.C.
3. IAEA Statute, Article XXI.C; as of April 2007, there were 144 member states of the IAEA.
4. IAEA Statute, Article XII.
5. A "principal nuclear facility" was defined as a reactor, a plant for processing nuclear material irradiated in a reactor, a plant for separating the isotopes of a nuclear material, a plant for processing or fabricating nuclear material (except a mine or ore processing plant), or a facility or plant of such other type as may be designated by the board, including associated storage facilities.
6. Later, however, such consent would occasionally be expressed through voluntary undertakings (such as those made by South Africa and Libya), and, less frequently, as a consequence of prior consent to be bound by action taken by the Security Council under Chapter VII of the United Nations Charter. Article 48 of Chapter VII of the Charter of the United Nations obliges all members of the United Nations to carry out the decisions of the Security Council under Chapter VII for the maintenance of international peace and security.
7. A treaty is an international agreement governed by international law between states concluded in written form between states and/or other entities with juridical personality (such as international organizations).
8. IAEA document INFCIRC/193, Agreement between the Kingdom of Belgium, the Kingdom of Denmark, the Federal Republic of Germany, Ireland, the Italian Republic, the Grand Duchy of Luxembourg, the Kingdom of the Netherlands, the European Atomic Energy Community, and the IAEA in Implementation of Article III.(1) and (4) of the NPT.
9. IAEA document INFCIRC/435, Agreement between Argentina, Brazil, the Brazil-Argentine Agency for Accounting and Control of Nuclear Material and the IAEA for the Application of Safeguards.
10. United Nations Treaty Service, Volume 294, Treaty Number I-4301, registered on 24 April 1958.
11. Resolution 1665 (XVI).
12. Resolution 2373 (XXII).
13. IAEA document INFCIRC/140.
14. The People's Republic of China, France, the Russian Federation, the United Kingdom, and the United States.
15. An excellent resource for those interested in a more in-depth analysis of the history of the NPT negotiations is the book by George Bunn, former General Counsel of the U.S. Arms Control and Disarmament Agency and one of the U.S. negotiators of the NPT cited the references above.
16. The United Kingdom, INFCIRC/263; the United States, INFCIRC/288; France, INFCIRC/290; the USSR (succeeded to by the Russian Federation), INFCIRC/327; and the People's Republic of China, INFCIRC/369.
17. By operation of this provision, it is only the application of safeguards under the other agreements that is suspended. The consequence of this is that the undertaking under an INFCIRC/66-type agreement (no military use) continues to apply with respect to items that had been subject to safeguards thereunder.
18. For a more detailed history of the development of export controls, the Zangger Committee, and the Nuclear Suppliers Group, see IAEA document INFCIRC/539 and the three revisions thereto.
19. As it turns out, in 1993, South Africa announced to the world that it had in fact had a nuclear weapons program, and that it had dismantled that program, and its six completed nuclear weapons, prior to becoming party to the NPT.
20. It is worth noting that board approval is not a precondition for the Secretariat to request access to information or locations pursuant to the provisions in comprehensive safeguards agreements related to special inspections.
21. IAEA document INFCIRC/474, 12 June 1995.
22. S/RES/1172 (1998).
23. IAEA statute.

Nuclear Energy and the Role of IAEA Safeguards: A Perspective from Brazil and Argentina

Sonia Fernndez Moreno and Marco A. Saraiva Marzo
Brazilian-Argentine Agencies for Accounting and Control of Nuclear Materials

This paper reflects only the views of the authors. The views expressed remain the exclusive responsibility of the named authors and do not necessarily reflect those of their governments.

We are witnessing the renaissance of nuclear energy as a suitable option to sustain socio-economic growth for future generations in a changing world where international security and peace are challenged by old and new realities. The nuclear weapons race is an increasing and frightening reality. Discussions and research are taking place to consider the actual use of such weapons. The nonproliferation and disarmament model of the 1950s is perceived as obsolete or insufficient by important actors. The Nuclear Nonproliferation Treaty (NPT) is put at serious strain and risk. Sustainable high safety has steadily become more important for public acceptance of nuclear energy and the validity of the framework for international technical cooperation on nuclear energy applications has been challenged. We need to urgently and convincingly respond to these realities to preserve peaceful nuclear energy development and applications. Undoubtedly, the IAEA is the most important collective forum to ensure the safe and peaceful expansion of nuclear energy for the benefit of mankind. The times we face demand the highest moral attitude from those decision-makers responsible for the definition of this new safe environment.

Dr. Mohamed ElBaradei opened his Director General's statement to the 2006 IAEA General Conference saying, "Anniversaries are a time of reflection and renewal. There is much to be learned by looking back on the fifty-year history of Atoms for Peace in its many applications—from the days of the first power reactor operations, safeguards inspections, safety guidance and transfer of nuclear technology, all the way to our program today..."

Guided by these inspiring thoughts, this article is written in an attempt to pay tribute to the people that have contributed to nuclear energy and to build the IAEA on its fiftieth anniversary and to share some ideas that may help to build responses to current challenges by presenting a joint perspective of the Agency's mission and activities along these years. Emphasis is given to its contribution to the development of peaceful nuclear energy throughout the establishment, maintenance and continuous improvement of an objective, technically oriented and nondiscriminatory safeguards. The paper looks both back and ahead on the IAEA's role to this end, and describes some views on what could be expected in the coming years.

Focusing on the agency's verification pillar, the most important contribution of safeguards to nuclear energy so far has been the implementation of reliable international verification of the peaceful nature of this technology serving both international cooperation and the development and expansion of peaceful nuclear energy worldwide. This has laid the foundation of the IAEA and it remains of vital importance today. This contribution to peaceful nuclear energy has been based on the collective confidence that safeguards have enjoyed along all these years. Moreover, safeguards as such continue to be a unique verification model dealing with a complex technology that was born with the stigma of mass destruction capability and it continues to confront us with such reality. It has also been unique in the sense of promoting nuclear energy applications and fuel-cycle activities under the "trust-but-verify" concept. The breaches of few states should not jeopardize the IAEA's safeguards as "the main pillar" of the nonproliferation regime, and principles and factors such as the *"bona fide"* principle among states, international cooperation, technical competence, and objectivity of safeguards must be kept as valid as ever to preserve their role in the future.

The challenges to nuclear nonproliferation and disarmament we faced in the last decade of the twentieth century and at the beginning of the twenty-first century, as well as the still slow but steady *renaissance* of nuclear energy as one of the clean-energy options to ensure sustainable development certainly demand to increase efforts to effectively respond to these new realities. We have the obligation to look ahead using the experience and the lessons learned in the past to reinforce an environment that provides the guarantees required in terms of safety, nonproliferation and disarmament to preserve the nuclear energy option unharmed for the generations to come.

Modern times are marked by the possession of nuclear weapons by new countries, the increase and sophistication of existing arsenals, the subtle change in the role of such weapons—deterrence against actual use—and the threat of the acquisition of this technology by non-state actors. At the same time, we observe an increasing interest in nuclear energy for peaceful applications. Different views and proposals on how to deal with the current challenges have been expressed in various forums. From those who support drastic decisions such as the limitation of nuclear fuel cycle technologies and knowledge, to those who are still making efforts towards increasing international cooperation, looking for a more modern international safeguards and encouraging real progress in disarmament as the main means to achieve a deal that enjoys international consensus. All these views and proposals have the inherent merit to share the concern that something has to be done urgently to stop the increasing threat posed by the spread of nuclear weapons in both horizontal and vertical directions. In our view, the actions to be agreed upon should not hamper the right and the possibility to develop nuclear energy technologies for peaceful purposes.

Based on our perception of past and present experiences on the implementation of IAEA's safeguards, particularly how the cooperation with IAEA has developed and increased under our regional scheme since the inception of the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC) and a reciprocal verification scheme between our two countries, we hold some striving expectations about the future for the evolution of safeguards, and more generally, for the protection of peaceful nuclear energy for the coming generations. As said earlier, for the latter to be successfully accomplished, a concerted and comprehensive effort of all states is required simultaneously in several complex areas. Looking ahead, some of our expectations can be summarized as follows:

- ***IAEA's safeguards continue to be the main pillar of the nonproliferation regime; efforts to maintain their credibility should be kept ongoing.***

A first expectation is that safeguards continue to be widely recognized by the international community as the main pillar to provide guarantees that nuclear activities are meant only for peaceful purposes. The collective sharing of this view would contribute to a further expansion of nuclear energy for the benefit of mankind. To increase the confidence in the IAEA's safeguards it is important to perform outreach activities aimed at promoting a better understanding of their capabilities and their limitations as well as the importance of cooperation, impartiality, technical competence and efficiency. In the past, we sadly heard views noting the loopholes and failures of IAEA's safeguards as if they were meant to provide 100 percent certainties that no undeclared nuclear program went undetected.

- ***IAEA's safeguards can and should be modernized and strengthened by increasing cooperation between the IAEA, the states and regional nonproliferation initiatives. The role and contribution of nuclear weapons-free zones should be furthered recognized.***

A second expectation, which should be coupled to the first one, is that safeguards can and should be modernized through increased cooperation to the maximum extent possible between the IAEA, states, and safeguards regional systems such as ABACC and Euratom in a way to further strengthen the confidence in the nonproliferation regime.

As part of our look into the past and future, the establishment of initiatives such as ABACC are worth pointing out. Within the efforts underway to improve IAEA's safeguards, we believe that promoting mechanisms similar to ours to other regions and encouraging a deepening of the cooperation between them and the IAEA could be one way to strengthen safeguards. That could be part of the concerted efforts toward establishing nuclear weapons-free zones in other regions of the world.

The Tlatelolco Treaty was the first Regional Weapons Free-Zone in an inhabited area of the world. This treaty came to be in 1967, before the NPT Treaty. It has been an important contribution to the nonproliferation regime that highlighted the prominent function of the IAEA's safeguards to fulfill states' nonproliferation commitments. Other weapons-free zone areas have followed this initiative, namely: The Treaties of Rarotonga, Bangkok, and Pelindaba. The role of the IAEA and the spirit of cooperation of regional countries have been of utmost importance to their successful conclusion. Such fruitful experience should continue to encourage the IAEA and its Director General to strengthen efforts towards establishing other Regional Weapons Free-Zone in areas of particular tension. Further efforts are also required for increasing the recognition of the real contribution of such agreements to the nonproliferation and the disarmament regimes. In our view, the importance of commitments assumed by states in a particular region to establish and maintain their territories free of nuclear weapons have not been yet fully recognized. More modern IAEA's safeguards should take the existence of such agreements into account and the IAEA has to increase the awareness of states about the value of these initiatives.

In our view, ABACC and the reciprocal system of accounting and control of nuclear materials (SCCC) that applies in both countries is a real example of what can be achieved in terms of transparency and a good way of increasing cooperation to improve international safeguards. It is also a useful example of countries' commitments of exclusively peaceful uses of nuclear energy.

The successful application of the SCCC for fifteen years and the atmosphere of cooperation between the countries, ABACC, and the IAEA in implementing international full scope safeguards, confirm the effective contribution to the nuclear nonproliferation regime of these initiatives.

We have reached the fiftieth anniversary of the IAEA and the fifteenth anniversary of ABACC and the SCCC. At this juncture, we could conclude that under appropriate circumstances, this process may well be useful for other countries and regions. Moreover, our expectation under the strengthening of IAEA's safeguards is to deepen this cooperation further up to the maximum extent envisaged in INFCIRC/153.

In fact, the issue of the cooperation between the IAEA and the State System for Accounting and Control (SSAC) has accompanied the evolution of safeguards since the very beginning. Various articles of INFCIRC/153 envisage for both national and regional SSAC a broader role in the implementation of IAEA's safeguards. Article 7 of INFCIRC/153, in particular, did refer to the scope of the verification of the States' findings, and the requirements of the Agency to take due account of the technical effectiveness of the SSAC. Moreover, the increased cooperation with state or regional systems was one of the measures identified in Part I of "Program 93+2" to improve safeguards efficiency and effectiveness. The Board approved these measures in 1995. It has also been an important element of integrated safeguards.

Increased cooperation with ABACC as well as with Euratom has demonstrated that further improvements on the effectiveness and efficiency of safeguards are possible. Technically effective SSAC should be considered to further increase cooperation without negatively affecting the concept of "independent conclusions." That can be considered together with a new and fresh way to do IAEA's traditional verification activities by which the agency retains the right to verify all, but in practice audit the SSAC's inspections and perform at random some verification on its own and focuses its attention to the more qualitative strengthening safeguards measures.

- ***IAEA's fifty years of experience in cooperation, verification, and safety should increasingly be recognized by states as important conditions to ensure the smooth and broad expansion of nuclear energy.***

A third expectations would be to maximize all these years of experience to suggest new ways to achieve good and reliable safeguards to come up with what might be a completely fresh approach to nuclear verification, not only in terms of the development of new technological methods, but also in terms of the establishment of new institutional concepts that complement or replace current practices and provide more effective but also more efficient and less costly safeguards. A review of the current conceptual safeguards framework with an innovative approach could be a good start. Equal attention should also be given to use such experience to improve technical cooperation and safety as a means to further promote the expansion of nuclear energy.

- ***IAEA's fifty years of experience should also be fully exploited to identify new and innovative ways to agree on other initiatives based on the full respect of the right to develop nuclear energy for peaceful applications in a safe and secure manner and to promote and expand technical cooperation.***

Expansion of nuclear energy requires a robust framework providing adequate confidence in the peaceful nature of such technology and its safe use. International safeguards will continue to be the main tool to offer guarantees on its peaceful nature.

Additional initiatives to further strengthen the nonproliferation regime like the multinational fuel-cycle approach, which is based on international cooperation and on voluntary schemes, may deserve further analysis. This is an area in which the IAEA has already played an important role.

In our view, for these initiatives to be successful it is important that they are not based on the limitation to the right to develop nuclear technology. We are aware that some of these ideas are focused on views affirming the close relationship of civil nuclear technology to nuclear weapons proliferation and thus the way to address proliferation is by limiting the technology. In fact, motivations and incentives to proliferate are dominant factors in deciding to pursue a nuclear weapons program, so imposing additional burden or limiting the civil nuclear activities do not seem to be a right path to follow.

- ***Effective progress in the disarmament area is of vital importance to nonproliferation. The IAEA's fifty years of experience can and should play a more prominent role.***

A fifth expectation for the future is to progress on nuclear disarmament under a credible international verification scheme in which the IAEA, with all the experience and expertise gained along these fifty years, could make a real difference.

Without going into much detail, it is crystal clear that efforts should be renewed to drastically discourage the possession of any form of nuclear weapons or nuclear explosive devices by states and non-state actors and to fully eliminate nuclear weapons.

Notwithstanding the fact that substantive discussions on this area should take place at the Disarmament Conference at Geneva, the IAEA and particularly its Director General have an important role to play to make this happen in the shortest possible time. Nonproliferation and disarmament are both sides of the same coin, to the extent that lack of progress in the latter would only contribute to the failure of the former. This does not imply that no actions are needed in the nonproliferation dimension to effectively respond to current challenges, but stresses the unquestionable fact that the international community must find innovative ways to fight against the perception that nuclear weapons, or the mere possibility of a country using the technology to develop such weapons, is a matter of prestige and power. Decisive efforts need to be made and practical steps need to be taken towards protecting nuclear technology for future generations and reducing the threat that weapons of mass destruction can fall in the hands of non-state actors.

Gradual but systematic reductions of stockpiles and their submission to international surveillance coupled with a cut-off fissile treaty that must also include international verification, the entry into force of the Comprehensive Test Ban Treaty (CTBT) and clear and verifiable commitments from nuclear weapon states—*de jure* or *de facto*—to separate fuel cycle activities and installations for peaceful uses from the ones dedicated to weapons are good examples of possible actions to discourage the possession of such weapons. Moreover, those countries with nuclear weapons should clearly separate the civil program and submit it to full scope safeguards, regardless of the verification modality that may be acceptable. As said before, the IAEA and its Director General have an outstanding role to play to assist the development of an action plan with proposals like the examples given in this article, or others that could really start making a difference in stopping the weapons race.

Final Remarks

We are confronting a multifaceted complex issue that calls for a comprehensive approach and a vision to international peace and security from all states. This integral approach goes from modernizing the United Nations system to drastically and truly reducing nuclear arsenals under credible international verification, while strengthening the confidence of the states in the IAEA's safeguards.

It is important to strengthen efforts towards establishing a "safeguards culture" that contributes to a good understanding among states of their contribution to nonproliferation and the peaceful uses of nuclear energy. Increased cooperation between the IAEA and the states is essential to better communicate and disseminate safeguards' role and functions.

There is not a one-fits-all formula to address old and new challenges, but we are convinced that there is a need for concerted actions be taken by all states to find innovative responses that enjoy consensus and provide a framework allowing the agency to fulfil its mandate of facilitating the expansion of nuclear energy for the benefit of mankind.

We believe that the actions and initiatives to be agreed upon should not hamper the right and the possibility of developing nuclear energy technologies for peaceful purposes. Regarding this, international cooperation and the IAEA play key roles. Proposals based on the denial or the limitation of nuclear technology for peaceful purposes do not seem to be adequate to build long-lasting responses to existing realities.

A significant contribution to nonproliferation would be the agreement on concrete steps and measures to discourage the possession of nuclear weapons. There is a need for real progress toward disarmament that includes an action plan at all levels to be a disincentive to the possession of nuclear weaponry.

In sum, we need to increase efforts to build an environment that enjoys international consensus to ensure a safe and peaceful use of nuclear energy for current and future generations. About this, Dr. ElBaradei's words, "In celebrating our fiftieth anniversary, our goal is to broaden awareness of the scope of the agency's mission and activities—our contributions to development, nuclear safety and security, and nuclear nonproliferation—and to provide forums to review the challenges and opportunities that lie ahead" are undoubtedly relevant.

Finally, we would like to express our appreciation for the opportunity given by the INMM to participate in this project to celebrate this important milestone of the IAEA through the special edition of the *JNMM* to present a broad perspective of the IAEA's role in these fifty years.

Five Decades of Safeguards and Directions for the Future: An Australian Perspective

John Carlson
Australian Safeguards and Nonproliferation Office, Barton, Australia

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

Abstract

An effective regime against the proliferation of nuclear weapons is essential to international peace and stability. The maintenance of an effective nonproliferation regime depends on credible verification, to provide confidence that nonproliferation commitments are being honoured. Under the Nuclear Nonproliferation Treaty (NPT) the verification task has been entrusted to the International Atomic Energy Agency (IAEA) safeguards system.

Credible safeguards are vital in reinforcing the commitment of parties to the NPT. If safeguards were seen as being deficient, confidence in the treaty would erode, leading to its failure. This places a heavy responsibility on the IAEA—and on member states whose support is needed by the IAEA.

Safeguards have come a long way from their inception as bilateral inspection arrangements, applied by nuclear suppliers. Following the establishment of the IAEA in 1957, an IAEA inspectorate was developed and bilateral inspections were gradually replaced by IAEA inspections. With the conclusion of the NPT in 1968, IAEA safeguards moved to a position of major international importance. The early focus on "item-specific" safeguards changed to full scope, or *comprehensive*, safeguards, applicable to all the nuclear material in a state.

By the mid-1990s the NPT had become almost universal. Over the same period there was substantial growth in national nuclear programs. The IAEA achieved considerable success developing and implementing a safeguards system able to cope with growing workload and complexity. There was however a serious flaw—an emphasis on declared material and facilities and systematic inspection activities resulted in substantial effort for areas of low proliferation risk, while inadequate attention was given to the problem of undeclared nuclear activities.

The latter has emerged as the major challenge to safeguards—the IAEA is under considerable pressure to establish a credible capability to detect undeclared activities. At the same time it must continue efficiency improvements, to achieve more effective performance from finite resources. Recent events have highlighted that safeguards credibility depends not only on technical capability but on preparedness to take appropriate decisions in case of noncompliance.

This paper outlines the major achievements of the safeguards system, the challenges now faced, and possible developments.

Introduction

Starting with Australia's major role in the founding of the United Nations after World War II, Australia has been a strong proponent of rules-based approaches to world order. This is reflected especially in our support for regimes against the proliferation of weapons of mass destruction, of which the nuclear nonproliferation regime is of fundamental importance. The centerpiece of this regime is the Nuclear Nonproliferation Treaty (NPT). A key feature of the NPT is its verification mechanism, the International Atomic Energy Agency (IAEA) safeguards system. As reflected in the adage "trust, but verify," credible verification has a vital part in reinforcing the commitment of NPT parties to the objectives of the treaty.

Through its role in underpinning the NPT, for almost four decades the IAEA has been closely involved in efforts to maintain international peace and security. This has been increasingly recognized by the media and the public, and in 2005 through the award of the Nobel Peace Prize. The "UN nuclear watchdog" has become a household name. Yet this period of increased recognition and attention has coincided with a period of growing challenge to the safeguards system and the nonproliferation regime.

The challenges are both political and technical. At the political level, there have been several cases of noncompliance with treaty obligations, two of which—Iran and the DPRK—remain ongoing. The technical challenges include the spread of proliferation-sensitive technology and the difficulties of detecting undeclared nuclear activities.

The safeguards system involves more than technical verification activities. The credibility of the system—whether the system meets the expectations of states—depends on confidence in two aspects: verification capability, and the outcomes that result from verification findings. Predictability and consistency of safeguards decisions are essential. This is particularly the case since the NPT itself has no mechanism for determining compliance—effectively this entrusted to the IAEA through decisions concerning compliance with safeguards agreements.

A fundamental safeguards objective is, through the risk of detection, to deter proliferation. But deterrence will be ineffectual if proliferators believe that the consequences of detection are low-risk. The IAEA secretariat and board must be prepared to identify noncompliance, and the international community must be prepared to take compliance action. The future of the safeguards system, and the NPT itself, depends on how well compliance issues are addressed.

Evolution of the *Traditional* Safeguards System

The prominent role that the IAEA now has in the international peace and security architecture took some time to evolve. The precursor of the IAEA safeguards system was the bilateral inspection arrangements developed in the early years of the nuclear industry. These inspections were conducted by nuclear suppliers and were "item-specific," i.e. they applied only to the particular item supplied. Following the establishment of the IAEA in 1957, an IAEA inspectorate was developed and bilateral inspection activities were gradually replaced by IAEA inspections.

A fundamental change in IAEA safeguards was introduced by the NPT, which was concluded in 1968. The NPT introduced a commitment by non-nuclear-weapon states (NNWS) to accept IAEA safeguards on **all** their holdings of nuclear material, existing and future, not only on supplied nuclear items. Thus the basis of IAEA safeguards changed from being "item-specific" to being "full-scope" (today termed *comprehensive* safeguards).

This change in emphasis had far-reaching consequences, though perhaps the implications were not fully appreciated at the time. The responsibility of applying full scope safeguards carries with it the responsibility to verify the absence of undeclared nuclear materials and activities. However, the *traditional* NPT safeguards system was primarily focused on verifying **declared** nuclear materials and activities, applying similar procedures to those developed for item-specific safeguards. It was generally assumed that development of fuel cycle capabilities independent of declared facilities would be beyond the resources of most states, and in any event would be readily detectable, and therefore if proliferation occurred it was most likely to involve diversion of nuclear material from declared facilities. As the discoveries made about Iraq's clandestine enrichment program in the early 1990s demonstrated, these were not well-founded assumptions.

For IAEA safeguards, the period until the mid-1990s was one of major growth and consolidation. There was substantial growth in nuclear power programs, and in the number of states with nuclear research activities. At the same time, membership of the NPT—hence the number of states under comprehensive safeguards—grew steadily. By the 1995 NPT Review and Extension Conference the treaty had become almost universal. The agency had considerable success developing and implementing a safeguards system that appeared able to deal with growing workload and complexity.

There was however a serious flaw—the emphasis on **declared** material and facilities and systematic inspection activities resulted in substantial safeguards effort going to areas of low proliferation risk. The practice of uniformity, and determination of safeguards effort on a facility-by-facility basis, led to the situation that in the 1990s some 60 percent of total safeguards effort was being allocated in just three states—Canada, Germany and Japan—based on the size and complexity of their fuel cycles and the quantities of nuclear material they held. But the safeguards violations that subsequently came to light showed that the actual risk of proliferation lay elsewhere, in states which under a uniform approach received few inspections. Inadequate attention was being given to the problem of undeclared nuclear activities. The dangers of this became apparent in Iraq—and we now know that during this period Iran had also embarked on a clandestine nuclear program.

Strengthening the Safeguards System

The discoveries in Iraq led to a wholesale reappraisal of how safeguards are designed and applied, a process that is very much ongoing today. This started with "Program 93+2," and led to the establishment of the additional protocol, together with a major program of technical development.

The program to strengthen safeguards is focusing particularly on establishing the technical capabilities and legal authority necessary for detection of undeclared nuclear activities. Central to these efforts is the effective use of information—involving collection and analysis of information that can enhance the IAEA's knowledge and understanding of nuclear programs—and providing more extensive rights of access to nuclear and nuclear-related locations, including for the resolution of questions arising from information analysis.

Underpinning the program to strengthen safeguards is the Additional Protocol (AP)—a legal instrument complementary to safeguards agreements, which establishes the agency's rights to more extensive information and physical access. The Model Additional Protocol was agreed upon by the Board of Governors in 1997. Of the sixty-four NNWS NPT parties with significant nuclear activities, today forty-five have APs in force and twelve have signed APs or had APs approved by the Board—an uptake of almost 90 percent of such states. The combination of a comprehensive safeguards agreement and an AP now represents the contemporary standard for NPT safeguards. It is of serious concern however that (at the time of writing) seven NNWS NPT Parties with significant nuclear activities have yet to adopt the AP—in addition Iran, which was applying the AP on a *provisional* basis, has now *suspended* its cooperation under the AP.

Challenges to the Safeguards System

The technical challenges include the spread of proliferation-sensitive technology—particularly the sale of centrifuge technology and even nuclear weapon designs through illicit networks—and the difficulties of detecting undeclared nuclear activities, which need not be industrial-scale to pose a proliferation threat.

Undeclared nuclear activities were involved with each of the five cases of safeguards noncompliance that have been reported by the IAEA Board of Governors to the Security Council—Iraq (1991), Romania (1992), DPRK (1993, and again in 2003), Libya (2004), and Iran (2006). Two of these cases—Iran and DPRK—remain ongoing. Iran in particular is defying the international community, and currently it is uncertain whether the international community has the will and the ability to take effective compliance action. Failure to satisfactorily resolve this situation will inevitably lead to regional proliferation pressures and a serious weakening of the NPT.

It may be unfair to the safeguards system to point out that Iran's clandestine nuclear activities went undetected for some twenty years—unfair because detection techniques, especially for centrifuge enrichment operations, remain under development; because the agency needs the access rights provided by the Additional Protocol, which Iran has refused to observe; and because national intelligence agencies also failed to detect these activities—but this situation is not reassuring, and illustrates very well the challenges facing the agency. It continues to be a major concern that we do not know the full extent of Iran's nuclear activities.

What do these developments mean for the IAEA safeguards system? Realistically, can the agency provide credible assurance that states do not have undeclared nuclear programs? This question goes to the heart of ongoing confidence in—and therefore commitment to—the NPT. A judgment about the performance of the safeguards system involves complex issues—it is essential to have a clear understanding of what the system can and cannot deliver, and to identify effective steps to address deficiencies.

The agency has decades of experience verifying non-diversion from declared nuclear activities, and conclusions in this regard can be reached with a high degree of confidence. Conclusions on the absence of undeclared nuclear activities, on the other hand, are necessarily qualitative, and safeguards may need to be complemented by confidence-building measures, particularly measures to enhance **transparency**. As will be discussed, transparency is likely to assume increasing importance in the nonproliferation regime.

New Directions for Safeguards Development

As discussed, the establishment of an effective capability to detect undeclared nuclear activities has emerged as the major technical challenge to safeguards. At the same time the agency is required to continue efficiency improvements, to achieve more effective performance from finite resources. Addressing the resources problem is not simply a question of increasing the safeguards budget, but also calls for a fundamental review of safeguards approaches and methods, to ensure the safeguards system is well-focused and cost-efficient. With the help of member states (e.g., through Safeguards Support Programs and SAGSI), the agency is making substantial progress in the redesign of the safeguards system.

Perhaps the most important single innovation in safeguards development is the introduction of the state-level approach (SLA). Safeguards are moving from the old uniform approach to one of differentiation, designing safeguards implementation to take account of state-specific factors, such as the acquisition paths available to individual states. The SLA meets effectiveness objectives, better focusing and prioritizing the application of safeguards resources, and in so doing also addresses cost-efficiency objectives. The challenge here is to be able to optimize the opportunities for flexibility provided by the SLA without introducing weaknesses in safeguards effectiveness. The development of the SLA, together with corresponding changes to ways of evaluating safeguards performance and reporting safeguards results, is a major undertaking, and will be a work in progress for some time.

Along with these fundamental changes in safeguards approaches, it has been necessary to develop a new range of verification methods and technologies. Although these techniques can be considered technical in nature, decisions on which measures should be applied and the intensity of their application—how much is *enough* to meet safeguards objectives—involve qualitative judgment. It is essential that the agency's conclusions on the absence of undeclared nuclear material/activities are credible. The international community must be confident that where the agency does not find indicators of safeguards breaches this does not simply reflect inadequate or ineffective verification effort.

Transparency is likely to become increasingly important, both as an integral part of the safeguards system and as a complement to the system. Transparency involves a number of aspects, including: transparency of the state to the agency; transparency of states to each other; and transparency of the agency itself.

Conclusions about the absence of undeclared nuclear activities are of necessity less definitive, less certain, than conclusions based on verification of declarations. Relatively, there may be less confidence in a more qualitative conclusion, but confidence can be reinforced by availability of additional information supporting the conclusion. There are many potential transparency mechanisms, including:

- wider publication by states of information on their nuclear programs;
- conduct of research and operational programs on a collaborative basis amongst states;
- broader privatization and globalization of nuclear activities, and establishment of multilateral fuel cycle centres; and
- conduct of collaborative safeguards activities on a bilateral or regional basis.

In particular, bilateral or regional safeguards arrangements could play an important role, complementing IAEA safeguards, in circumstances where states are looking for additional confidence-building measures—the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC) is a valuable precedent here.

Enhanced cooperation with and transparency towards the IAEA will be particularly important. Strengthened safeguards bring new requirements for states in terms of information, access, and cooperation. It is no longer sufficient for a state to meet only its minimum legal commitments to the agency (although that is always a good start!)—rather, states need to cooperate with the agency to the standard necessary to maintain the confidence of the international community. This includes showing full transparency to the agency, particularly where there are issues of compliance or confidence-building to be resolved. A particular challenge to the agency will be developing a sufficiently rigorous method of testing transparency and drawing appropriate conclusions—failure to cooperate may be obvious, but where the state appears to be cooperating it will be important to avoid being misled, not to draw broader conclusions than are actually warranted.

Transparency is also important for the safeguards system itself. To be most effective in its confidence-building function, a verification system must have an appropriate degree of transparency. To have confidence in the conclusions reached, states must have sufficient knowledge of how the system works, including verification methods, performance standards, quality assurance and decision-making processes. The agency is devoting considerable effort to these matters. One mechanism that might be looked at here is external review—just as there is an external auditor for budgetary performance, there may be a role for an external auditor for safeguards performance.

A related issue is the extent to which information available to the safeguards system should be shared with states. A notable aspect of traditional safeguards is **confidentiality**—information held on a state is maintained within the agency and not shared with others. The Chemical Weapons Convention (CWC)—a newer treaty than the NPT—establishes a different approach. States' declarations are made available to all parties. Other states thus have the opportunity to cross-check information declared against information available to them, e.g., through their own analysis, research, or national technical means. This helps identify discrepancies in information that might require investigation, and helps establish the credibility of the verification agency's operations. This is a direction the safeguards system might usefully take. Obviously there are difficult issues, such as maintaining confidentiality of sensitive information, and avoiding warning a state of investigations in progress—but a more transparent system, where greater information is available on states' nuclear activities, the IAEA's activities, its conclusions and the basis for these, would have important confidence-building benefits.

Compliance Issues

Recent events have highlighted that safeguards credibility depends not only on technical capability but on preparedness to take appropriate decisions in case of noncompliance. Inevitably political as well as technical considerations come into play in dealing with noncompliance. It is essential however to avoid confusion between technical and political dimensions. Noncompliance as such involves technical judgments, and a noncompliance finding should be based primarily on technical grounds.

Political factors will come to the fore in efforts to resolve the situation after a noncompliance finding has been reached. The distinction between technical and political aspects is reflected in the IAEA statute, which requires noncompliance findings to be reported to the Security Council. The statute also requires the agency to notify the Security Council of matters arising that are within the Council's competence, i.e., matters pertaining to international peace and security.[1] This is a clear indication that political decisions are the responsibility of the Security Council.

In the Iranian case, concern about the consequences of a noncompliance finding—e.g., whether Iran would cease cooperation with the agency, or even withdraw from the NPT, and whether in any event the Security Council could agree on a response—led to what amounted to plea-bargaining within the Board of Governors, under which a noncompliance finding was withheld for three years while efforts were made to negotiate a solution.

At the time this may have seemed a pragmatic response to a very difficult situation, but the mixing of technical and political considerations risked severe damage to the integrity and credibility of the IAEA's processes. Not only did the delay in the noncompliance finding embolden Iran, but it even led some to argue that noncompliance had ceased to be noncompliance with the passage of time—in effect, that a clandestine program became legitimate once it had been discovered and investigated. This was never a valid argument in the Iranian case, since to this day we do not know the full extent of Iran's clandestine nuclear program, but the fact such arguments were advanced shows the need not to delay a noncompliance finding once the facts are sufficient to warrant this. The Iran case cannot be considered a good precedent for the handling of any future case.

Predictability and consistency are important to any rules-based process—to this end the Board of Governors itself should not be beyond transparency, the application of guidelines to assist the Board in making compliance decisions would help ensure confidence in those decisions.

Conclusions

IAEA safeguards have provided a unique model of treaty compliance verification, with a rigorous process for identifying noncompliance. However, as safeguards become more qualitative—reflecting the nature of contemporary safeguards challenges—compliance issues are becoming more complex. We are in a period of transition, from the apparent certainty of the traditional safeguards processes, to a more judgment-based approach, based on broader information and likely to be less absolute in its outcomes.

The apparent certainty of traditional safeguards was misleading, and led to an expectation by some of an unrealistically high evidentiary standard. In fact, proof of noncompliance is unlikely to ever be forthcoming—it can be assumed that a state about to be caught red-handed will refuse inspectors access rather than cooperate in the discovery of irrefutable proof of noncompliance.

The less-certain world of qualitative safeguards was anticipated in INFCIRC/153, when it established an alternative route for reporting apparent noncompliance to the Security Council. The IAEA statute[2] provides for noncompliance to be reported to the Council—but, as discussed, not all noncompliance will be easy to determine. So it is that INFCIRC/153[3] refers to diversion to nuclear weapons or to purposes unknown. Further, INFCIRC/153 provides for the agency to report to the Security Council if it is unable to verify that there has been no diversion to nuclear weapons.[4] It is sufficient for the agency to show that diversion—removal of nuclear material from safeguards or discovery of undeclared nuclear material—has occurred and the purpose of the diversion is not known—and that diversion to nuclear weapons is plausible in the circumstances (e.g., having regard to the nature and quantity of the material involved).

Accordingly, the phrase "purposes unknown" will assume greater significance. Also likely to assume greater importance is the statute's requirement, not used until recently in the Iranian case, for the agency to notify the Security Council of questions arising that are within the competence of the council. This could apply to uncertain compliance issues, or concerns about future noncompliance, or simply the destabilising effect that the development of sensitive nuclear technology could have in a region of tension.

The fact that safeguards are becoming more qualitative—or at least, that there is increasing recognition that safeguards involve a substantial qualitative element—does not mean that safeguards judgments will become less technical and more political. On the contrary, the agency's value to the international community is its ability to report facts and impartial technical analysis. It is essential to the agency's credibility that safeguards reporting and decisions continue to be based on objective technical grounds. Ensuring this in a more qualitative environment requires greater clarity of thought about the safeguards mission, and greater transparency in the processes involved.

The nuclear nonproliferation regime is a rules-based system in which verification plays a fundamental role. The agency's safeguards system provides an essential service in the form of an impartial mechanism for demonstrating compliance. How well it continues to do so in the future depends on how successfully the agency itself, and the international community as a whole, address challenges such as those outlined here. It is essential for the safeguards system to have the necessary technical competence and integrity of process. It is in the interest of all parties to contribute constructively towards achieving these objectives.

Notes

1. Article III.B.4
2. Article III.B.4
3. Article XII.C
4. Paragraph 28
5. Paragraph 19

Safeguards in Canada: Some Reflections on the Past, Present, and Future

James A. Casterton and Michael A. Kent
International Safeguards Division, Canadian Nuclear Safety Commission, Ottawa, Canada

The views expressed in this paper are those of the authors.

Abstract

The fiftieth anniversary of the International Atomic Energy Agency (IAEA) is an appropriate time to examine safeguards implementation in general as well as in specific states. This paper will do so primarily in the context of the Canadian experience. It will briefly examine Canada's past and current experiences in the development and implementation of safeguards in Canada pursuant to the Canada/IAEA safeguards agreement and the Additional Protocol to that agreement. It will also offer some views on future directions for safeguards implementation in Canada. In addition to discussion of safeguards concepts, approaches and implementation strategies relevant to the Canadian situation, the paper will also address the role played by the Canadian Safeguards Support Program in contributing to safeguards implementation in Canada and more generally.

Introduction

Discussion of the Canadian contribution to international safeguards must be framed within Canada's long-standing political commitment to the peaceful use of nuclear energy. Since signing the trilateral "Declaration on Atomic Energy" with the United States and the United Kingdom in November 1945, successive Canadian governments have been committed to preventing "the use of atomic energy for destructive purposes." To this end, Canada played a leading role in the negotiations of the Treaty on the Nonproliferation of Nuclear Weapons (NPT) and was one of the first states to sign the treaty in 1969. Under Article III of the NPT, a non-nuclear-weapon state such as Canada is required to conclude a safeguards agreement with the International Atomic Energy Agency (IAEA) to verify compliance with Article II. Article II of the NPT requires a non-nuclear-weapon state party to undertake not to receive the transfer of, control, manufacture, or otherwise acquire nuclear weapons or other nuclear explosive devices. Canada also played a significant role in developing the concepts and approaches underlying the safeguards agreement required pursuant to Article III and as set out in the IAEA Information Circular 153 (Corrected) titled, The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Nonproliferation of Nuclear Weapons. This safeguards agreement is commonly referred to as the comprehensive safeguards agreement (CSA) or as INFCIRC/153 safeguards. In 1972, Canada was one of the first countries with a significant nuclear program to bring into force a CSA, thereby establishing the basis for verifiable international assurance of its commitment to the peaceful use of nuclear energy.

For the next three decades, Canada assisted the IAEA in improving and strengthening the safeguards system to ensure the continued credible, relevant, and reliable verification of states' peaceful use commitments pursuant to the NPT. As noted below, this was undertaken in the context of Canada's domestic natural uranium fuel cycle and in a broader international context. Principle among the international efforts was Canadian participation in the development of the Model Protocol Additional to the Agreement(s) Between State(s) and the International Atomic Energy Agency for the Application of Safeguards as set out in IAEA Information Circular 540(Corrected). Commonly referred to as the Additional Protocol or as INFCIRC/540, this document provides the agency enhanced information on and greater physical access to a state's nuclear and nuclear-related activities thereby establishing the basis for the IAEA to draw a more comprehensive conclusion about a non-nuclear weapon state's compliance with its NPT commitments.

Shortly after the 1945 declaration, the Canadian government brought into force the Atomic Energy Control Act for the "control and supervision of the development, application, and use of atomic energy and to enable Canada to participate effectively in measures of international control of atomic energy." The act and its associated regulations were implemented by the Atomic Energy Control Board (AECB). Canada updated its nuclear legislation in 2000 with the promulgation of the Nuclear Safety and Control Act (NSCA), which established the Canadian Nuclear Safety Commission (CNSC) to replace the AECB. Pursuant to the NSCA, the CNSC is mandated to "regulate the use of nuclear energy and materials to protect health, safety, security, and the environment and to respect Canada's international commitments on the peaceful use of nuclear energy." Pursuant to this regulatory approach, the CNSC and its predecessor—the AECB—have been charged with implementing the Canada/IAEA safeguards agreements and fulfilling Canada's commitments under those agreements as the designated State System of Accounting for and Control of Nuclear Material (SSAC) for Canada. At the time of the IAEA's fiftieth anniversary, it is appropriate to examine the evolution of safeguards within the Canadian context, with respect to the past, present, and future, and to discuss the safeguards concepts, approaches, and implementation strategies relevant to the Canadian situation.

Table 1. Some important Canadian dates relevant to safeguards

November 1945	Canada/U.S./UK Declaration on Atomic Energy
August 1946	Atomic Energy Control Act enacted
January 1969	Nuclear Nonproliferation Treaty ratified
February 1972	Canada/IAEA Safeguards Agreement entered into force
May 2000	Nuclear Safety and Control Act enacted
September 2000	Additional Protocol entered into force
March 2001	Initial Declarations submitted
September 2005	Broad Safeguards Conclusion attained

The Early Years

After 1945, while other countries were developing commercial nuclear power reactors based on light-water technology, Canada concentrated on continuing its work on the development of natural uranium reactor technology and the associated supporting infrastructure. The Canadian technology, known as CANDU, uses natural uranium as fuel and deuterium as moderator. Continuous on-load fuelling means the reactor does not need to be shut down periodically for re-fuelling. This unique technology presented a challenge from a safeguards perspective. Through the AECB, Canada worked extensively with the IAEA in developing effective safeguards approaches for CANDU reactor and for the supporting fuel cycle activities (e.g., natural uranium conversion and fuel fabrication). One of the principal ways of achieving this objective was through the provision of Canadian expertise on the CANDU system to the IAEA on a cost-free basis. This complemented conceptualization and development work that was ongoing within Canada through a consultative process with the IAEA.

One of the primary challenges with the reactor technology was to address the possible diversion of irradiated fuel as it travelled from the reactor core to the underwater irradiated fuel storage bays. This diversion scenario was addressed by developing a safeguards scheme that included a containment and surveillance system encompassing the reactor core, the irradiated fuel transfer routes and the irradiated fuel bays. Equipment such as closed-circuit television cameras, E-type wire-seals, Yes/No radiation monitors, and irradiated-fuel bundle counters supported this scheme. As safeguards approaches were formalized and accepted for the nuclear power reactors, the agency and the AECB began to develop and implement safeguards on the other fuel cycle facilities and on the research laboratories. As the nuclear industry grew, additional measures were required to complete an effective safeguards regime for all of the fuel cycle facilities.

Pursuing effectiveness was the hallmark of early safeguards efforts in Canada. However, as the Canadian fuel cycle grew it became apparent that it was consuming a significant proportion of the IAEA's limited safeguards resources. Together with the agency, the AECB worked on developing safeguards concepts, approaches and strategies that would improve the efficiency of safeguards implementation in Canada without undermining its overall effectiveness.

Discussions between the IAEA and the AECB concerning alternative safeguards approaches for the Canadian natural uranium fuel cycle began in 1982 with initial efforts focused on what became known as the "zone approach" for natural uranium. This approach was developed and tested through extensive field trials at Canadian facilities and was eventually reflected in the IAEA's safeguards criteria. In the zone approach, all of Canada's natural uranium fuel cycle facilities (i.e., the natural uranium conversion and fuel fabrication facilities and the fresh fuel storage areas at the nuclear power reactors) are considered a single area for the purposes of inventory verification. One of the principal objectives of this approach was to dramatically reduce the inspector effort needed to verify transfers between facilities within the zone. Rather than independent facility verifications dispersed throughout the year, the IAEA conducts an annual simultaneous physical inventory verification of all the natural uranium facilities. This approach was feasible in Canada due to the geographic concentration and the relatively small number of facilities, the single type of nuclear material used in the fuel cycle, and the facilities' desire to optimize implementation of the existing safeguards regime. Gains from the zone approach have included reduced IAEA inspection days and overall greater efficiency through lower costs to the facilities and greater recognition of state-as-a-whole considerations. Success in this area would not have been possible without the assistance by the facility operators and close cooperation between the IAEA and the AECB.

During this time, in cooperation with the IAEA and the industry, field trials at domestic facilities were also undertaken to demonstrate the possibility of using unannounced inspections rather than traditional scheduled inspections at Canadian facilities. This concept became known as Any Time/Any Place inspections or ATAP. The AECB also worked with the IAEA in the early 1990s on the development of the near real-time reporting concept and on new safeguards-relevant instrumentation, including technology to provide remote monitoring and measurement of discharged fuel from the CANDU reactors, both of which were designed to replace traditional inspector effort. Some of these early concepts and approaches proved to be useful in the context of subsequent consideration of measures to strengthen the IAEA's safeguards system, particularly those efforts leading to the development of the Additional Protocol.

To support many of the safeguards initiatives undertaken between Canada and the IAEA the Canadian Safeguards Support Program (CSSP) was created in 1976. The program's objective is to improve the efficiency and effectiveness of safeguards by providing assistance to the IAEA in the areas of safeguards approaches, techniques, and procedures; development of safeguards equipment and ongoing support; information technology and processing; infrastructure support (e.g., quality management); and training of IAEA staff. An important element of program delivery was the provision of cost-free experts to the IAEA, particularly for the development of safeguards approaches and technology transfer. As agreed with the IAEA, the original focus of the CSSP was assistance in the development of safeguards approaches for CANDU reactors coupled with the development of instrumentation required by the safeguards approach. Many of the approaches and equipment developed through the CSSP for the IAEA in Canada are also utilized for safeguards on exported Canadian nuclear technology in countries such as South Korea, Argentina and Romania and for the general application of safeguards around the world.

Current Experience

With the signing of the Additional Protocol in 1998, and its entry into force in 2000, the newly created CNSC began to implement the IAEA's strengthened safeguards system. Preparations for this began before the actual ratification of the Additional Protocol, when the CNSC worked with the domestic industry to prepare draft declarations which were reviewed with the IAEA to ensure conformity with the protocol's specific requirements. During this time, issues such as the definition of nuclear sites were settled through informal consultation between the CNSC, the industry and the IAEA to ensure that the final, formal declarations were appropriate and consistent in terms of content and format.

For Canada, bringing the Additional Protocol into force satisfied two objectives: (i) it demonstrated Canada's continued commitment to the peaceful use of nuclear energy; and (ii) it enabled the IAEA to acquire the basis for drawing a broader safeguards conclusion, which, once drawn, would lead to further optimization of safeguards implementation. The agency's broader safeguards conclusion that all nuclear material in Canada remains in peaceful activities is based upon the determination that there is no indication of diversion of declared nuclear material from peaceful activities or of undeclared nuclear material or activities. Such a conclusion provides the highest level of confidence that Canada is in compliance with its peaceful use commitments.

The road to the conclusion, however, was long and winding and presented several challenges. The first challenge was to satisfactorily address questions regarding Canada's nuclear activities that predated the 1972 safeguards agreement. The CNSC and the agency worked together to resolve these issues which covered a period of over thirty years. The fact that records during this period often did not exist in a manner consistent with safeguards requirements compounded the difficulty in trying to establish precise information on activities undertaken during this period. The second challenge was the reinterpretation of the starting point of safeguards by the agency in 2003. For Canada, this policy amendment extended safeguards coverage to the natural uranium refinery at Blind River, Ontario, and the natural uranium conversion facility at Port Hope, Ontario. The challenge for all concerned—the agency, the CNSC, and the facility operators—was to develop an appropriate safeguards approach for facilities where the agency had no previous experience and that were not built with safeguards implementation in mind. Together, the CNSC and the agency, working with the operators, established an accountancy structure including material balance areas and key measurement points, developed the procedures and techniques for verification, and agreed on an approach for accounting for the large historical inventories of uranium-bearing scrap and waste.

The IAEA reached the broad safeguards conclusion for Canada in September 2005. Since that time, the CNSC has been working with the IAEA and with Canadian industry to transition from strengthened safeguards to a state-level integrated safeguards approach. As with the case of the Additional Protocol preparations, consultations with the agency on the nature and scope of such an approach for Canada had begun well before the broad conclusion was drawn. In fact, such consultations were initially undertaken in the mid-1990s in the context of the agency's early efforts to conceptualize and develop integrated safeguards. The CSSP was particularly useful during this period as it sponsored initial trials of an integrated safeguards approach for Canada—an approach that featured the provision of near-real-time information on nuclear material flows through the fuel cycle by means of electronic mailboxes, the remote transmission of data from installed safeguards equipment, and the use of short-notice and/or unannounced inspections. The CSSP also continued to work on enhanced instrumentation such as the digital Cerenkov viewing device (DCVD) and the core discharge monitor (CDM) as well as on new technologies such as the application of geospatial information systems (GIS) and satellite imagery for inspection use.

Additionally, the CNSC and the IAEA established a bilateral working group as well as trilateral working groups with the domestic nuclear industry to assist in the conceptual development of the state-level integrated safeguards approach and to address implementation matters. While the responsibility for developing and approving the state-level integrated safeguards approach for Canada was vested in the IAEA, the consultation mechanisms enabled the CNSC to keep the Canadian nuclear industry informed of the nature and scope of the changes to safeguards implementation and to seek appropriate industry input into this change process.

The CNSC and the IAEA have agreed to pursue the implementation of the state-level integrated safeguards approach on a "phasing-in" basis in accordance with agreed priorities and consistent with available resources. The first priority was the development and implementation of an integrated safeguards approach for transfers of irradiated fuel to dry storage at multi-unit nuclear power stations in Canada. Under the traditional safeguards approach, such transfers were consuming over half of the IAEA's person-days of inspection (PDIs) at the multi-unit stations with the anticipation of significant increases in inspection effort as the number of transfers per facility increased over time.[1] Two new facilities would also begin transfers in late-2007, additionally augmenting the inspection burden. The issue was identified as a growing concern by both the IAEA's Director General and the Deputy Director General for safeguards and, in response, the CNSC submitted a conceptual paper outlining a new approach to the IAEA in 2003. This provided a focus for subsequent discussions and testing.

Under the traditional approach, inspector presence was required for all four steps of the transfer process: to verify the irradiated fuel before loading into modules; to witness the loading of the modules into the dry-storage container (DSC); to escort the DSC between the dry storage bay and the storage facility; and to prepare the DSC for long-term storage by applying seals and by taking a radiological profile. Under the new integrated safeguards approach, continual inspector presence is replaced by an unannounced inspection regime, which is supported by regular information on each proposed and actual transfer. Inspector presence is still required at the end of the process to apply seals and to take the radiological profile of each DSC prior to transfer into the final storage area. Possible savings for the agency in the inspection of irradiated fuel transfers to dry storage at multi-unit stations could be as high as 60–75 percent of the traditional effort, depending upon the level of detection probability utilized. For the facilities affected, the new approach allows much greater flexibility in their transfer schedule, as constant coordination with agency inspectors is no longer required. For the CNSC, implementation of the new approach requires no new additional resources.

Into the Future

The CNSC continues to work in cooperation with the IAEA and the domestic nuclear industry to transition to the full implementation of the state-level integrated safeguards approach. Thus far, the approach is being implemented in a sector of the Canadian nuclear program comprising six small research reactors, three static dry storage facilities, and two locations outside facilities (LOFs). As noted above, an integrated safeguards approach is also being applied to the transfer of irradiated fuel to dry storage at the multi-unit power reactor stations. Work continues with the agency to develop the procedures for the implementation of the state-level integrated safeguards approach at the front end of the natural uranium fuel cycle. This includes the natural uranium processing facilities such as refinement, conversion, and fuel fabrication as well as the fresh fuel storage areas of the nuclear power reactors. In addition, work is required on the development of procedures for multi-unit power reactor facilities, for the single-unit power reactor facilities, for transfers of irradiated fuel at the single unit power reactors, and for the Chalk River Research Laboratory. At the appropriate stages in this process, in keeping with previous practices, consultations will be required with the various facility operators. Completion of these tasks will lead to the full implementation of state-level integrated safeguards. However, the job will not be finished. Ongoing effort will be required to monitor and improve this approach as experience is gained and as new technologies are developed. Accordingly, the quest for maximizing safeguards efficiency while maintaining safeguards effectiveness will continue.

Implementation of the state-level integrated safeguards approach is dependent upon the IAEA's ability to maintain the broad safeguards conclusion for Canada. This, in turn, will require the continued successful implementation of Canada/IAEA safeguards agreements. As Canada's SSAC, the CNSC is committed to ensuring that this objective is consistently attained. One essential element of this effort is to ensure that there is an appropriate regulatory framework to provide assurance to Canadians, as well as the international community and the IAEA, that nuclear material in Canada is properly accounted for and that it is being used solely for peaceful purposes.

In addition to the ongoing work on the state-level integrated safeguards approach and on the successful implementation of the Canada/IAEA safeguards agreements, the very real prospects of a nuclear renaissance in Canada and in other countries will present new challenges to safeguards implementation. In Canada, efforts have begun with respect to the refurbishment of some of the existing nuclear power reactors and the construction of new ones. Additionally, new uranium mines and associated facilities may be needed to replace aging infrastructure and to ramp up production to meet future demand.

The future work of the CSSP will focus on addressing these challenges through the development of new safeguards measures and technologies to optimize the implementation of the state-level integrated safeguards approach in Canada. Information analysis techniques and processes—including the utilization of information portals and geospatial information systems—novel technologies for detection of undeclared activities, next generation gamma/neutron monitoring equipment, extension of the application of radar and hyper-spectral satellite imagery are some of the tasks to be undertaken. As with previous CSSP efforts, these will apply to safeguards implementation in Canada as well as in other countries.

Conclusion

The IAEA's safeguards system is an essential element of the nuclear nonproliferation regime. As the only international agency vested with the responsibility of providing independent conclusions about a state's conformity with its peaceful use commitments, the IAEA has played a vital role in the pursuit of nuclear nonproliferation goals. To do so, the concepts, approaches, and measures that were the basis of the original safeguards system have had to change over time. While this change has been significant in recent years, it can be argued that the nature and pace of change to the system will be greater in the future than any previously experienced. The essence of these changes is centered on the agency's effort to implement state-level approaches under different safeguards scenarios. Among other factors, this will require fundamental changes in safeguards culture—a move away from uniformity to a more focused and adaptable safeguards system that continues to provide confidence in the various safeguards conclusions drawn by the IAEA. In the context of the state-level integrated safeguards approach for Canada, this should involve continued focus on those elements of the fuel cycle that are strategically significant, such as those involving direct-use nuclear material, and less emphasis on nuclear materials of low proliferation significance such as depleted, natural and low-enriched uranium.

Canada has a long, demonstrated commitment to nuclear nonproliferation. It is within this framework that Canada has sought to contribute to the development of an effective safeguards system that is efficiently implemented. Cooperation and consultation with the IAEA and with Canadian industry in the spirit of openness and transparency have been the principal characteristics of CNSC's efforts to contribute to meeting this objective. At the same time, Canada has worked to ensure that we have an appropriate regulatory framework in place to meet the obligations that have been made. This approach has helped CNSC to effectively contribute to safeguards implementation in the first fifty years of the IAEA's existence and it will undoubtedly continue to be fundamental to Canada's contribution to the IAEA's ongoing efforts to improve safeguards during the next fifty years.

Note:

1. For example, each transfer utilizes approximately three person days of inspection (PDIs). In 2006, approximately 250 PDIs were consumed in this area with the expectation that this level could increase to more than 1,000 PDIs in the not-too-distant future.

Fifty Years of the International Atomic Energy Agency and German Contributions to the Development of International Safeguards

Hans Hermann Remagen
Bundesministerium fuer Wirtschaft und Technologie, Bonn, Germany

Arnold Rezniczek
UBA GmbH, Herzogenrath, Germany

Bernd Richter and Gotthard Stein
Forschungszentrum Juelich, Juelich, Germany

Abstract

During the years 2006 and 2007, the International Atomic Energy Agency (IAEA) has been celebrating its fiftieth anniversary. This background gave good reasons for both a retrospective of the evolution of agency safeguards and the identification of future challenges in safeguards. This paper will highlight some German contributions to the development of agency safeguards during the last thirty years. The major contributions and projects were not only of a technical nature but also addressed conceptual as well as institutional issues. The principal framework for the developmental cooperation between the IAEA and the German government has been the Joint Program on the Technical Development and Further Improvement of IAEA Safeguards, dubbed the German Support Program. Currently, it is comprising more than twenty individual tasks. In addition to highlights and current tasks, the structure and management of the German Support Program will be briefly explained.

Introduction

There are two essential reasons for Germany's continuing strong relationship with the International Atomic Energy Agency (IAEA) and its nuclear materials controls. Initially, Germany embarked on a complex and comprehensive nuclear program making an early and *a priori* commitment with regard to the nonproliferation of nuclear weapons. Secondly, in connection with her foundation, the Federal Republic of Germany renounced the acquisition of weapons of mass destruction.

In Germany, there have been very early experiences with nuclear safeguards, initially based on bilateral agreements in connection with the import of nuclear materials and technologies, later in connection with the multinational controls implemented by the Euratom Safeguards Directorate in the framework of the Treaty Establishing the European Atomic Energy Community.

Therefore, it is not surprising that representatives from the German industry and research establishments played an important role when formulating and establishing the international nuclear material controls in the framework of the Treaty on the Nonproliferation of Nuclear Weapons of 1968 (NPT). An important German boundary condition had been the prevention of industrial espionage. To this end, Germany was in favor of structuring the nuclear material controls in a way that they should focus on and be restricted to strategically important parts of the nuclear facilities. Yet, there was a strong resentment in Germany, when an overwhelmingly great part of the safeguards effort was spent in the non-nuclear weapons states with large nuclear programs. It is expected that this drawback can be overcome by the deployment of the new Model Protocol Additional to the Agreement(s) between State(s) and the IAEA for the Application of Safeguards, dubbed the Additional Protocol.[1] In the future, safeguards efforts can be better concentrated on problem areas, as needed. Following the establishment of the IAEA, the German safeguards contributions were provided mainly in the framework of the Joint Program on the Technical Development and Further Improvement of IAEA Safeguards between the Government of the Federal Republic of Germany and the IAEA, dubbed the German Support Program.

The German Program in Support of the IAEA

The German Support Program was established in the autumn of 1978 and relates to the NPT, which requires its parties to cooperate with the IAEA. The support program objectives are the early information of the IAEA about nuclear plans and projects in Germany as well as the joint development of safeguards methods and techniques; furthermore, consultancy support is provided and experts are delegated to the IAEA. In order to enhance the effectiveness and efficiency of IAEA and Euratom Safeguards, the responsible directorates of the European Commission are represented in the steering committees of the German Support Program, while Euratom is also invited to actively participate in the development projects. Last but not least, the technical projects have the objective to enable commercial companies to compete in a high-technology market segment.

In 2007, the German Support Program consisted of about twenty-five active tasks. Since its establishment, more than 150 tasks have been performed. The achievements have been documented in almost 360 progress reports. Fourteen experts were delegated to the IAEA, in order to provide support on a temporary basis. Depending on the work programs, different working groups were formed to do the research and development. Working group members were delegated from the relevant nuclear industry, national research centers, universities, commercial developers and manufacturers, and government agencies. Various tasks were performed in cooperation with other Member States' Support Programs. In 1983, the German Support Program reached a maximum of thirty-eight active tasks.

During its first decade, the support program concentrated on the development of measurement methods and techniques, designed for nuclear material controls in fuel cycle facilities such as fuel fabrication and spent fuel reprocessing. In the 1990s, the majority of tasks focused on the development of containment and surveillance methods and instruments. This change reflected the new German nuclear policy: abandoning the plans to develop and implement new reactor types as well as fuel cycle activities in favor of long-term storage of spent fuel and its direct final disposal in geological formations.

By the end of 2006, the German government had provided more than 13 million euros of funding under the support program. In addition, the German industry and national research establishments had spent about 50 million euros for investigations and developments related to the German Support Program. The government spent about an additional million euros in the frame of national technology promotion.

The IAEA approved many of the technical systems developed under the German Support Program for routine safeguards use. While the German government holds the intellectual property rights, IAEA and Euratom are not charged license fees when procuring safeguards equipment developed under the German Support Program. Some types of equipment have also been implemented in bilateral disarmament and armament control programs.

Major German Development Activities

Safeguards Concepts and Approaches

During the first decade of the German Support Program, the main activities were driven by the need for developing safeguards concepts for nuclear fuel cycle facilities that were under construction or already in operation.[2] Important German contributions related to the front end of the nuclear fuel cycle focused on developing safeguards measures for gas centrifuge enrichment plants. This work was performed in connection with the Hexapartite Safeguards Project with participation of IAEA and Euratom. Results of these analyses and negotiations resulted in the Limited Frequency Unannounced Access (LFUA) approach for cascade areas, in order to meet the requirements for safeguards effectiveness without jeopardizing the protection of classified know-how.

In connection with the planning of the German commercial spent fuel reprocessing plant at Wackersdorf safeguards development started at a very early stage.[3,4] In fact, the very first task under the German Support Program concerned the development of safeguards for reprocessing. The IAEA was already involved during the plant design stage, in order to ensure an optimum nuclear material control. Furthermore, considerable effort was spent to develop near-real-time nuclear material accounting (NRTA) for reprocessing plants.

For the commercial mixed oxide fuel fabrication plant at Hanau a new safeguards concept was developed, Flow Batch Operations Monitoring (FBOM).[5] It allows for a continuous production on the part of the operator while enabling, for safeguards purposes, the in-plant monitoring of material batches with identical plutonium vectors.

The THTR-300 power plant with pebble-bed reactor was characterized by its spherical fuel elements with highly enriched uranium as well as by its on-load refuelling operation. At the SNR-300 power plant with fast sodium-cooled breeder reactor the fresh fuel was stored under sodium and, thus, was inaccessible for remeasurement. It was necessary to take these special features into account when developing safeguards approaches for these new power plant reactors.[6,7] New technical solutions and appropriate inspection profiles were designed.

Last but not least, starting in the 1980s, comprehensive development activities took place related to the final disposal of spent nuclear fuel in geological formations. A technically feasible safeguards concept was developed for a final repository in rock salt.

Issues related to the implementation of the Additional Protocol started to be addressed in 1996, i.e., eight years before entering into force in the European Union. The first step was to draw up a list of companies that might fall under the Additional Protocol. The according IAEA and Euratom lists contained more than 100 facilities and "locations-outside-facilities," where nuclear material was handled, as well as about 190 holders of small quantities. Most of these establishments used the material for non-nuclear applications such as depleted uranium for shielding. A number of these facilities did not even exist any more, when the Additional Protocol entered into force on April 30, 2004. Therefore, the task was to reduce the list of candidate installations to the virtually relevant institutions.[8,9]

Investigations were also necessary for those national research centers that originally were almost exclusively dedicated to the development of nuclear techniques. In the meantime, however, the majority of activities in these establishments concern research with no relationship to nuclear engineering. Here, a site definition procedure was developed for the purpose of the Additional Protocol that focused on laboratories with nuclear relevance. The first proposal was made in 1999 for the Juelich Research Center with its nuclear research portion then being down to 5 percent. This example raised some interest also in other IAEA member states.

Introduction of Remote Sensing for Safeguards

In the course of the Iraq war of 1990-1991, one state's government presented satellite images to the IAEA showing undeclared nuclear facilities in Iraq as a proof for Iraq's violation of the NPT. As these images were classified due to their origin, it had not been possible to use them as a proof of evidence in the UN Security Council. It was easy for the Iraqi government to claim that the images were manipulated. In order to analyse the applicability of commercially available satellite imagery for IAEA safeguards purposes, experts from the Juelich Research Center initiated a cooperation with the King's College London. At the 1994 IAEA Symposium in Vienna, results were presented from analysing several locations where undeclared nuclear activities had been suspected. The results were so convincing that, hence, the investigations continued in the frame of the support programs of Germany, United Kingdom, Canada, and the United States. Finally, the IAEA established its Satellite Imagery Analysis Laboratory. The advantage of commercial satellite imagery is that it can be acquired not only by the IAEA but also by an accused government that can no longer claim the falsification of the images.

Under the German Support Program basically two evaluation methods for remote sensing data were developed: (1) Multivariate Alteration Detection (MAD) method and (2) object-oriented analysis method. Figure 1 shows the principle of the MAD method taking the Gorleben sites of the long-term interim storage facility for spent fuel and highly radioactive waste and the PKA pilot conditioning plant as an example. In the vicinity, there is also the exploratory salt mine which may become a nuclear repository site. Three LANDSAT TM5 images were acquired that were taken in August 1984, 1989, and 1991 (top row). By applying the MAD method to the 1984/1989 and 1989/1991 image pairs the changes were extracted and displayed (bottom row). To facilitate interpretation the images were combined with a high-resolution KVR-1000 image, with alterations being highlighted in different colors. The bottom left picture shows, [originally] in red, the salt excavated from the underground and deposited on a pile appearing in rectangular shape in the bottom right corner. The bottom right picture shows, also [originally] in red, the then newly built pilot conditioning plant in triangular shape in the top left corner.[10]

Figure 2 shows an automated object-oriented analysis taking a nuclear power plant as an example. The method requires a reference database comprising a number of known facilities but of different types, in order to determine fundamental features of such facilities. Fundamental features of a nuclear power plant

Figure 1. Case study of Multivariate Alteration Detection (MAD), Courtesy: Dr. I. Niemeyer

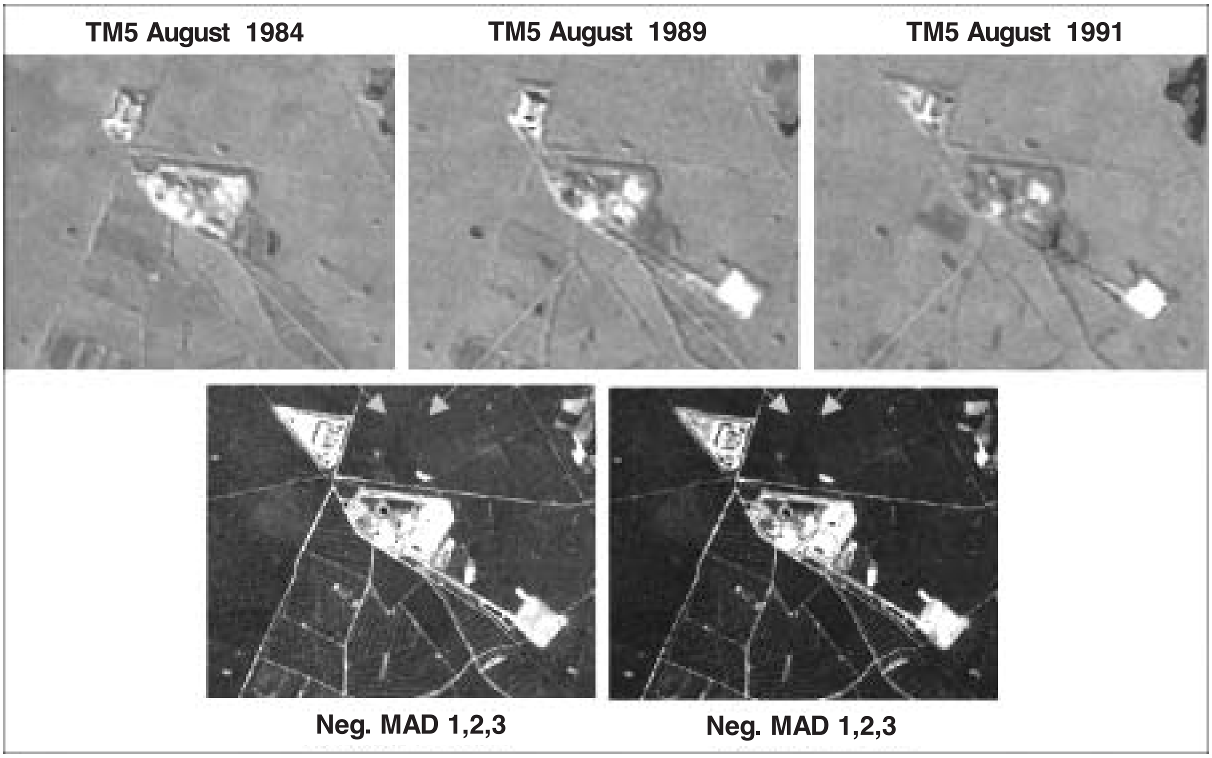
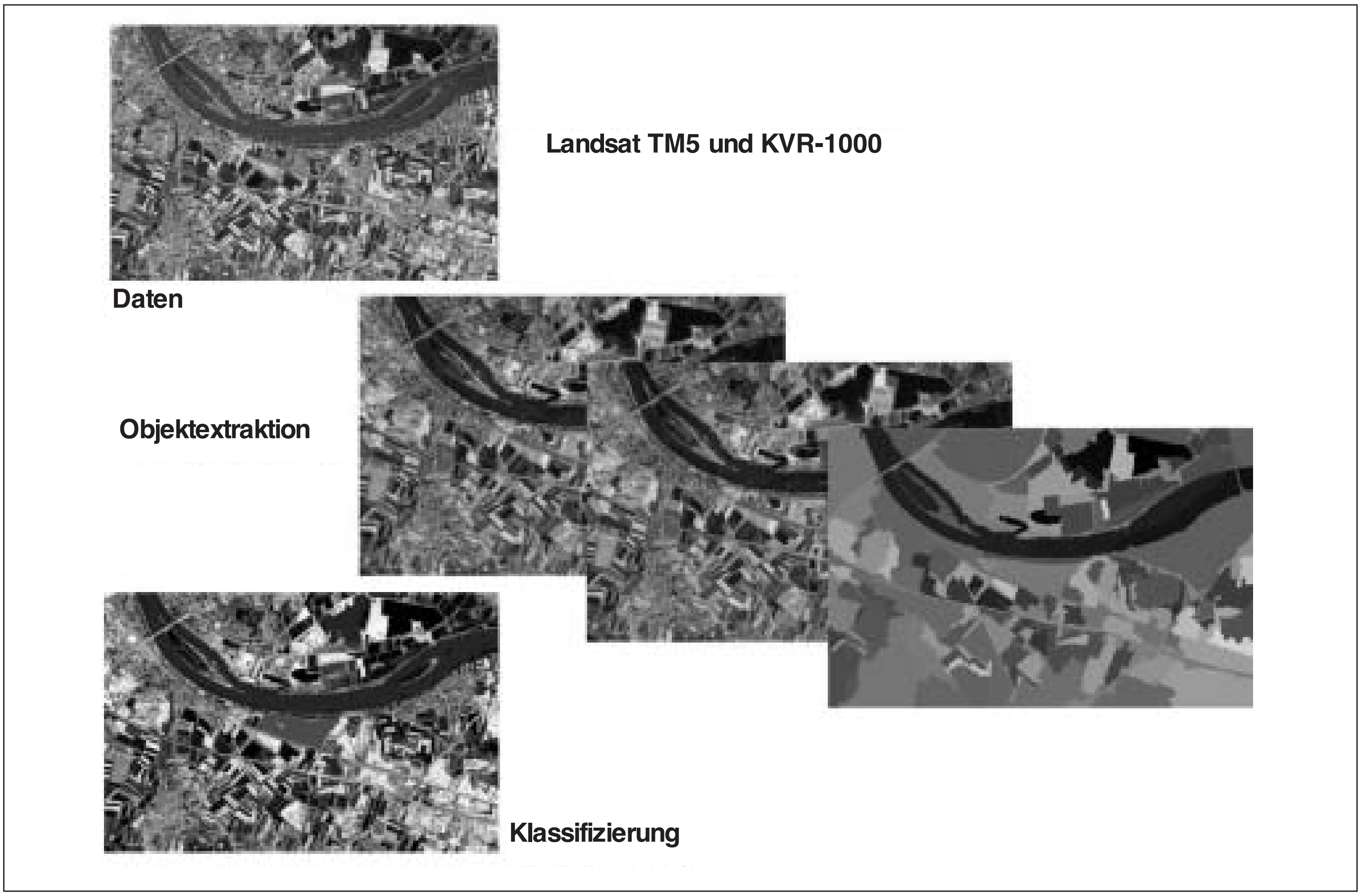


Figure 2. Case study of object-oriented analysis, Courtesy: Dr. I. Niemeyer



would be geometries of reactor and turbine buildings, cooling tower, its shadow, and the vicinity of a river. In the example, the reference database comprised LANDSAT TM5 images from five known facilities. These images were combined with KVR-1000 data. The result of classifying an *unknown* site is shown in the bottom left picture. The automated classification yielded a river in blue, the power plant in red, the cooling tower in green, and its shadow in yellow. The example shows the Muelheim-Kaerlich nuclear power plant located at the Rhine River.

Collection, Treatment, and Evaluation of Safeguards Data

This research and development area is characterized by mathematical investigations, for example, in statistics and game theory. Essential progress was achieved by developing statistical methods and algorithms for the control of nuclear fuel cycle facilities, in which the material is handled in bulk form. An example is the computer Program for the Statistical Analysis (PROSA) of data acquired in near-real-time material accounting.[11,12,13]

Another development was the Safeguards Performance Evaluation System (SPESY).[14] It is an expert system designed to allow systematic planning and evaluation of IAEA inspections by taking the particular safeguards implementation criteria of the respective type of nuclear facility into account.

Another project concerned the development of a game-theoretical model for inspection strategies (to detect diversion of nuclear material in a timely manner). The model is characterized by a decision tree. The application of the model yields the result that there is no need for unannounced inspections, in order to achieve a predefined detection probability.[15]

Important initial results in this area of the German Support Program were the development of a nuclear material accountancy system for nuclear research centers[16,17,18] and supporting the IAEA in establishing its safeguards information system ISIS,[19] which is currently being re-engineered.

Measurement Methods and Techniques

Work in this area is related to the development of systems and methods as well as to the assessment of methods. To the end of monitoring the fuel handling in the core of the SNR-300 power plant reactor the nuclear industry developed the Inaccessible Inventory Instrumentation System (IIIS).[20] IAEA and Euratom had already approved the system for inspection use, when the political decision was made, not to take the plant into operation.

Early in the 1980s, in the frame of the Hexapartite

Figure 3. Hybrid K-edge densitometer, Courtesy: CEC/JRC/ITU Karlsruhe

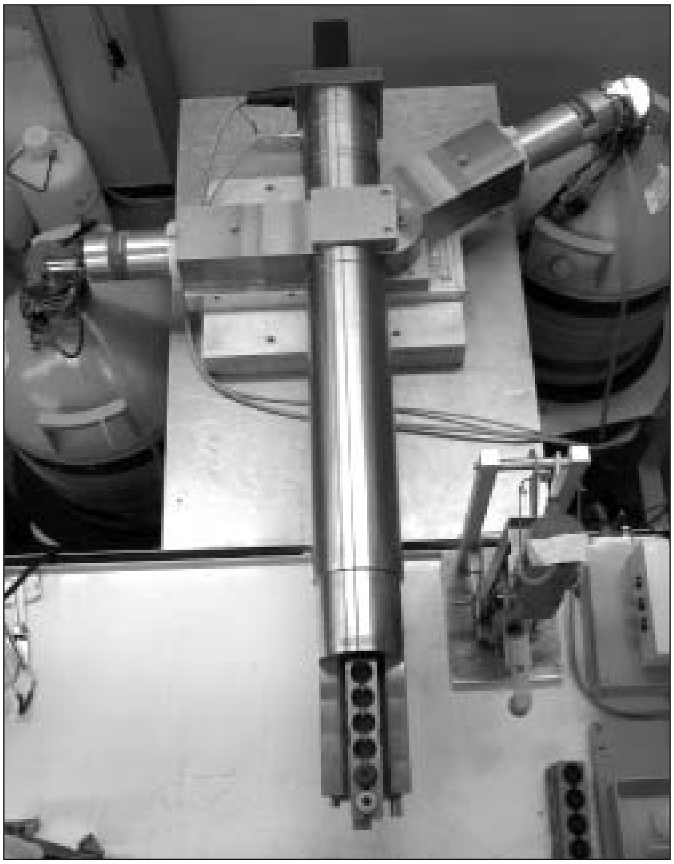


Figure 4. Gamma spectrometer with mini multi-channel analyzer Courtesy: IAEA and GBS-Elektronik GmbH

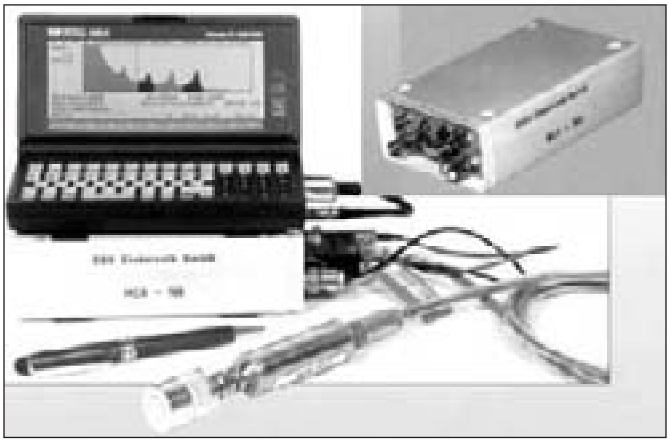


Figure 5. Criticality tester, Courtesy: IAEA

Safeguards Project, the problem was to develop and evaluate safeguards measures proposed for commercial gas centrifuge enrichment facilities. Until today, such facilities together with spent fuel reprocessing facilities are considered to be particularly proliferation relevant. A comprehensive field test was performed, in order to assess the applicability of high-resolution gamma spectroscopy at the surface of uranium-hexafluoride piping. The result was, that it is not possible to determine the uranium-235 enrichment in the Urenco facilities at Almelo and Gronau without taking classified operational parameters into account.[21]

The development of the Hybrid K-edge Densitometer at Karlsruhe Research Center was a great success. A renowned manufacturer of nuclear instrumentation obtained a license to produce and distribute the instrument that combines K-edge densitometry and K-X-ray fluorescence measurements. It is designed to allow determination of uranium and plutonium concentrations in input and product solutions of a reprocessing plant.[22,23] So far, twenty units of this system have been implemented on a worldwide basis (see Figure 3).

Early in the 1990s, the miniaturized multi-channel analyzer MiniMCA was developed at the Rossendorf Research Center.[24] Initially, the MiniMCA had 4,000 channels and was the most powerful instrument of its type. Thanks to its user-friendliness it became one of the inspectors' favorite devices. The IAEA is using more than 200 units, while also Euratom and various national authorities are using the MiniMCA. Outside safeguards, it is applied in environmental monitoring and physical protection. Figure 4 shows a portable gamma spectrometer consisting of a palmtop PC, a cadmium-zinc-telluride detector, and a MiniMCA, shown separately in the upper right corner.

Another development was the criticality tester designed to enable verification of the fuel inventory of a zero power research reactor or critical assembly.[25,26] The criticality tester consists of a software package developed by the Dresden Technical University and hardware configured from a MiniMCA, a helium-3 neutron detector, and a PC (see Figure 5). The extended version is the core inventory verifier,[27] which has three neutron detectors and is conceived for the verification of the core inventory of large research reactors in the megawatt power scale.

For a commercially available hand-held gamma spectrometer,[28] a safeguards specific user software and interface were developed. The following functionality is realized: acquisition of gamma

Figure 6. HM-5 measuring unit
Courtesy: M. Alexander

energy spectra, automated qualitative determination of uranium and plutonium, active length verification (e.g., of fuel rods), identification of isotopes, and measurement of uranium enrichment. In the IAEA, the instrument is known as HM-5 unit with about 120 units being in use (see Figure 6). The European Commission has some fifty units in use, both for Euratom safeguards and at the Joint Research Center.

A digital multi-channel analyzer is being developed for unattended applications.[29] Its major features are: modular design, low power consumption, local data storage, uninterrupted power supply by backup battery, data authentication and encryption, remote monitoring capability, and remote maintenance capability. It is possible to use the device with different types of radiation detector and achieve a high spectral resolution at high counting rates.

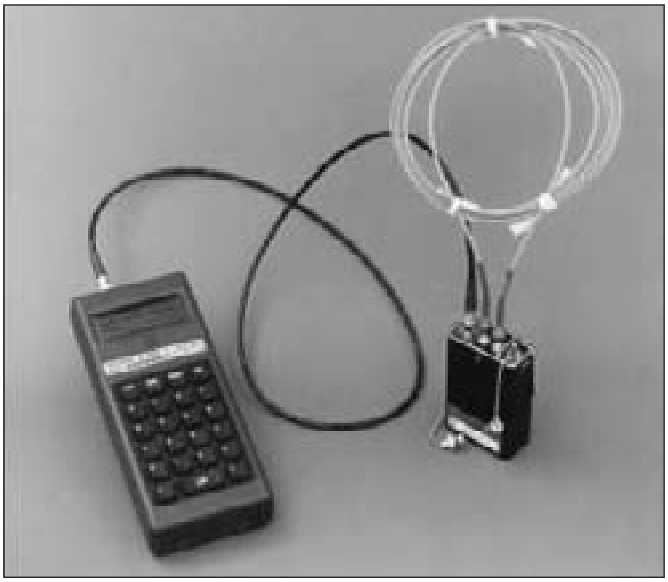
Containment and Surveillance Techniques

Containment and surveillance techniques provide a potential to reduce on-site inspection effort. Initially, the IAEA relied on seals and cameras available for physical protection purposes. However, it turned out that such instrumentation had a limited value for safeguards applications, unless it was modified to meet safeguards-specific requirements such as high reliability, large data storage capacity, tamper resistance, data authentication, modular design, remote data transmission, and integration with other safeguards systems.

In order to improve the situation, the German Support Program focused on safeguards specific developments. Investigations yielded new principal equipment standards, which were not only accepted for containment and surveillance instrumentation but also for unattended measuring systems. In addition, it became necessary to develop criteria and procedures for the qualification and authorization of instrumentation developed for safeguards. A German cost-free expert started to cope with this problem that is now sufficiently solved.[30] Today, the IAEA has a climate chamber, cooperates with the European Joint Research Center in the testing and characterizing of electronic instrumentation, and cooperates with the Viennese Atom Institute in the performance of irradiation tests.

Data authentication was an indispensable principle that was not realized and implemented by the IAEA. The German Support Program addressed the issue in the mid-1980s and started a development project, initially for optical surveillance data.[31] The objective was to provide the IAEA with assurance that origin, time, and content of the data were authentic. The first applicable technique became the tamper-resistant TV-link implemented in the IAEA's Multi-camera Optical Surveillance (MOS) system.[32]

Figure 7. VACOSS electronic seal system including seal reader
Courtesy: Forschungszentrum Juelich

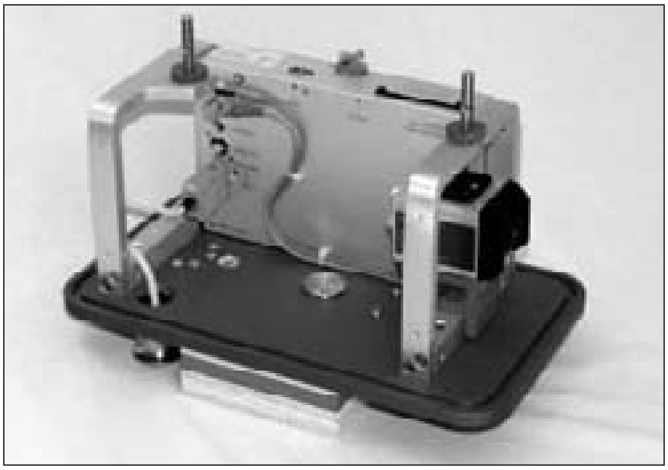


In order to reduce the amount of optical data, the applicability of scene change detection in the camera unit was investigated and realized.[33] An operational mode could be demonstrated where a sequence of images immediately before and after a scene change was recorded. In this connection, the feasibility of delayed remote retrieval of digital surveillance images from a nuclear facility was demonstrated.[34] The investigations and field test results yielded invaluable information with regard to remote monitoring schemes that might be implemented by now under the Additional Protocol.

The German Support Program focused on electronic sealing systems. The development of the Variable Coding Sealing System (VACOSS) (see Figure 7) was a long-term project.[35] The seal wire is a fiber optic cable. Its opening and closing times and dates are recorded in the seal and can be retrieved via an interface. While initially a dedicated reading device was required, now the seal can be handled using a palmtop PC. The seal provides for encoded remote data retrieval. It is battery-operated, reusable, and can be interlaced with other VACOSS seals. In this application, each one of these seals can be interrogated individually via the joint data and power cable or party line.[36] The advantage of this type of operation is that, while the seals are applied in the control area, their interface can be located outside the control area, so that the inspector is not affected by an unduly high radiation level during repeated seal interrogations. The IAEA has about 2,000 VACOSS seals in use that, after more than fifteen years of deployment, will be

Figure 8. EOSS electronic seal, Courtesy: Dr. Neumann Consultants

Figure 9. Single camera unit consisting of DCM14 data module and CCD-camera, Courtesy: Dr. Neumann Consultants



replaced in the near future. Although developed under the German Support Program, VACOSS is being manufactured and distributed by a company in the United States.

In connection with the decommissioning of the high-temperature reactor power plants AVR at Juelich and THTR-300 at Hamm-Uentrop, a solution was found to save on-site inspection efforts. All the spherical fuel assemblies had to be transferred from the reactor sites to the Ahaus long-term interim storage facility. For safeguards purposes, a concept was realized where the VACOSS seal could be coupled to an optical surveillance system. By means of a dedicated user terminal, the plant operator, in the absence of a safeguards inspector, was able to attach or detach a VACOSS seal under camera surveillance with the seal data being recorded not only in the seal but also in the associated surveillance images. IAEA and Euratom were able to save considerable on-site inspector effort, while the plant operators were more flexible in their plant operations.

In 2006, the IAEA began to implement a replacement program for the VACOSS seal. In the future, the IAEA will use the Electronic Optical Seal System (EOSS), which was also developed under the German Support Program (see Figure 8).[37] EOSS has a lower power consumption and a higher data storage capacity than VACOSS. In addition, the following features are realized: data authentication and encryption, remote data retrieval, output of a trigger signal, e.g., to initialize image acquisition by an optical surveillance system, or to enable integrated data evaluation, i.e., in combination with data acquired in parallel with measuring and camera systems.

In thrillers, a favorite scenario is that of a thief manipulating the surveillance camera system by introducing old images with no anomalies. This suggested developing for the IAEA a technical concept for tamper-resistant image transmission. The development was initiated on the basis of the IAEA's tamper-resistant blue standard camera housing that provided space not only for a camera but also for a data transmission module. Manipulation of the camera and data module would be indicated by anomalies of the IAEA camera housing. The concept of the tamper-resistant data transmission module consists of the following features: camera signals are directly fed into the data module, authenticated, and transmitted out of the secure camera housing, via ordinary cabling, to a central data collect station, e.g., a server PC. Here, the corresponding data receiving module checks the incoming data for authenticity. Having said this, the tamper-resistant TV-link (TRTL)[38] consists of a module pair, i.e., a data transmission module and a receiving module, while the data transfer between the two units can be performed using an *insecure* cable. TRTL was first developed data authentication method for analogue video frames and, later, was the core component of the MOS System.

In the early 1990s, MOS was the first multi-camera optical surveillance system that was purely based on safeguards user requirements. Also part of the MOS System concept was the above mentioned dedicated user terminal for VACOSS-MOS operation.[39]

The implementation of various video techniques provided also by other member states support programs raised the IAEA's desire to acquire as many images as possible, i.e., the picture taking frequency was increased drastically. The drawback was that also the reviewing effort increased drastically. The IAEA quickly called for a review station for video images that could be capable of supporting the review of all four types of video systems in the IAEA's use. The video systems differed by video norm and form factors of videotape cassettes. To this end, under the German Support Program the Multi-System Optical Review (MORE) Station was developed.[40] It was also designed to select those images, which showed scene changes with respect to preceding frames. For each camera's field-of-view the inspector would set relevant regions-of-interest where scene changes would trigger the inspector's alert. By means of the MORE Station, IAEA and

Euratom were able to significantly increase their effectiveness and efficiency. Previously, the inspector had to review each frame individually, whereas with MORE he was able to run an automatic tape review at normal play speed with the relevant images being selected in his absence. Then, he looked at the selected images, while he was still able to replay all the rest of them, if required.

The image processing principle realized in MORE was later implemented in the camera module. The feasibility of front end data reduction was demonstrated in a field trial. Front end data reduction is important for remote monitoring schemes, in order to limit the volume of data to be transmitted.

In the 1990s, the DCM14-based family of digital video systems was developed.[41,42] Fielding by the IAEA started in 1998 on a worldwide basis. For the first time, the IAEA introduced but one of its kind safeguards system. DCM14 systems were also deployed by the United Nations Monitoring, Verification and Inspection Commission (UNMOVIC). The DCM14-techniques comprises single-camera systems for different applications and the multi-camera system DMOS[43] with up to thirty-two camera channels.

Figure 9 shows a single camera unit consisting of a CCD-camera and a DCM14-camera module; the tamper-resistant camera housing is not shown. The features of this camera unit are: local data storage on a PC card; two picture taking modes (1) constant time interval, (2) scene change detection with sequence of images taken before and after the event; data authentication and encryption, user authorization; remote data retrieval; power saving mode and battery operation; output of various trigger signals; compatibility with different types of CCD-cameras.

In 2005, the IAEA in cooperation with the German and U.S. Support Programs started the development project on its next generation surveillance system. The IAEA's intention is to start fielding the new optical surveillance system in 2009, at a time, when the DCM14-technique will have been in use for ten years.

Summary

The major results of the German Program in Support of the IAEA, which was established in 1978, can be summarized as follows:

- Development of facility specific safeguards approaches for nuclear research centers as well as for the total nuclear fuel cycle including direct final disposal of spent nuclear fuel in a geological repository;[44]
- development of a system for statistical analysis of data from near real-time accounting;
- development of an expert system for the assessment of safeguards effectiveness;
- development of game-theoretical models for inspection strategies;
- implementation of remote sensing for safeguards and development of analysis methods for satellite imagery;
- support of the IAEA in the implementation of the Additional Protocol including "site definition" for former nuclear research centers;
- development and implementation of data authentication;
- development and implementation of the concept of a safeguards specific sensor head using the DCM14-camera as an example;
- development of review methods for optical surveillance data;
- demonstration of front end scene change detection in the camera head, for data reduction;
- demonstration of remote data transmission with delayed retrieval of image data;
- support of the IAEA in implementing quality standards for instrumentation specifically developed for safeguards.

The IAEA approved the following systems for inspection use:

- Hybrid K-edge densitometer;
- miniaturized multi-channel analyzer MiniMCA;
- hand-held gamma spectrometer HM-5;
- electronic safeguards sealing systems VACOSS and EOSS;
- multi-camera optical surveillance system MOS with VACOSS-MOS interface and user terminal;
- tamper-resistant TV-link TRTL for analogue video systems;
- multi-system optical review station MORE;
- DCM14-based family of digital surveillance systems.

As a result it can be stated that most of the developments have been implemented by the IAEA for routine inspection use. Euratom started implementing safeguards instrumentation developed under the German Support Program in a larger scale only after the entering into force of the Additional Protocol. This has been due to changes in their safeguards strategy.

For the German government the funding of its support program has paid off in the evident and recognized enhancement of IAEA safeguards. On the other hand, German developers and manufacturers of safeguards instrumentation have gained by contributing to the German economy. All this was not possible without fruitful and close cooperation between IAEA, Euratom, technical experts, German nuclear facility operators, instrument developers and manufacturers in Germany and abroad, research establishments, government agencies, universities, and other IAEA Member States Support Programs.

Also in the future, the IAEA will have to rely on Member States Support Programs including the German Support Program. This will be of particular importance in connection with the further implementation of the Additional Protocol, which requires the IAEA to focus on the detection of undeclared nuclear activities and materials. Especially this complex task requires new national and multi-national cooperation of experts from very different scientific areas, in order to continuously improve the requested detection capabilities and efficiency. In the future, Germany will play an important role in supporting the IAEA, as it has in the last fifty years.

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Hans Hermann Remagen, Dr. rer. nat., doctorate in nuclear chemistry, is currently employed by the German Federal Ministry for Economics and Technology and since 1978 has been involved in international nuclear safeguards, initially as an inspector of the International Atomic Energy Agency, afterwards in the German nuclear industry and German government.

Arnold Rezniczek, Dipl.-Ing., electrical engineering and management science, since 1975 has been involved in research and development of international nuclear safeguards methods and techniques, currently working as an independent consultant and is chair of the ESARDA working group on integrated safeguards.

Bernd Richter, Dr. rer. nat., doctorate in experimental nuclear physics, currently employed by the Juelich Research Center, since 1978 has been involved in research and development of international nuclear safeguards methods and techniques, chair of the ESARDA working group on containment and surveillance, JNMM *associate editor for international safeguards.*

Gotthard Stein, Dr. rer. nat., doctorate in experimental nuclear physics, retired from the Juelich Research Center, since 1974 involved in research and development of international nuclear safeguards methods and techniques, German representative in the IAEA Standing Advisory Group on Safeguards Implementation, JNMM *associate editor for international safeguards.*

Toward Effective and Efficient IAEA Safeguards: Review of Collaborations Between Japan and the Agency

Kaoru Naito
Nuclear Material Control Center (NMCC), Tokyo, Japan

Nobuhiro Muroya
Ministry of Education, Culture, Sports, Science and Technology (MEXT), Tokyo, Japan

Abstract

Japan, firmly committed to nuclear nonproliferation, ratified the Nuclear Nonproliferation Treaty (NPT) in 1976, and placed herself under obligation, as a non-nuclear weapons state, not to produce or acquire nuclear weapons. Recognizing the important role of the NPT and associated IAEA (International Atomic Energy Agency) safeguards in achieving nonproliferation, Japan has been upholding the NPT regime and exerting her efforts in realizing efficient and effective IAEA safeguards. This paper outlines the nonproliferation policy of Japan and reviews the historical development, the current situation and the future direction of collaborations between Japan and the agency toward the establishment of effective and efficient IAEA safeguards system.

Introduction

Japan's Commitment to Nonproliferation

Japan, as the only nation in the world to suffer an atomic bombing, has been firmly committed to nuclear disarmament and nonproliferation, being inspired by the strong national sentiment calling for the total elimination of nuclear weapons. Ratifying the Nuclear Nonproliferation Treaty (NPT) in 1976, she placed herself under obligation, as a non-nuclear weapons state, not to produce or acquire nuclear weapons. Furthermore, Japan's domestic law, the Atomic Energy Basic Law, requires Japan's nuclear activities to be conducted only for peaceful purposes. In addition, Three Non-Nuclear Principles were adopted by the Japanese government in 1967 as her policy guideline and has been reaffirmed by the successive governments, proclaiming the principles of "not possessing, not producing, and not permitting the introduction of nuclear weapons into Japan." These points clearly testify that Japan has no intent to possess nuclear weapons. She has strongly upheld the NPT regime and considers that the strengthening of international and regional/national safeguards is a vital element for improving the global nonproliferation regime. This commitment of the Japanese government to nuclear nonproliferation was reaffirmed in the Framework for Nuclear Energy Policy adopted by the Atomic Energy Commission (AEC) of Japan and endorsed by the Cabinet resolution of October 14, 2005.[1]

Founding and Upholding IAEA Safeguards System Prior to the NPT

Japan played a major role in founding and supporting the agency safeguards system soon after the creation of the IAEA in 1957. While states welcomed the newly created agency, there was some initial resistance to the implementation of IAEA safeguards. When the first member and Director of the IAEA's Safeguards Division was appointed in July 1958, Japan was expected to be the first nation in which the agency would apply safeguards to Japan Research Reactor (JRR)-3 and its fuel. On September 23 of that year, Japan requested that the IAEA provide three tons of natural uranium in metallic form for JRR-3. The board invited those states that had offered nuclear materials to submit tenders for the fuel. Canada offered, in effect, to donate the fuel to the IAEA; the offer was accepted and the IAEA Board of Governors approved the first supply and project agreements between the IAEA and a member state. Through this, Japan and Canada aimed at breathing life into the safeguards provisions of the IAEA Statute. In January 1959, the board approved a set of ad hoc safeguards for the JRR-3 reactor.[2]

Further, Japan also made significant contributions to the establishment of more generic safeguards scheme, or the adoption by the Board of the documents describing the agency's safeguards system, such as INFCIRC/26 (1961) and later INFCIRC/66 (1965) with its revisions (1966 and 1968).[3] Based on INFCIRC/26 and the safeguards transfer agreement between Japan, the United States, and the IAEA, the agency conducted the first safeguards inspections in Japan, May 8-16, 1964, at several research reactors and critical assemblies.[4] When the NPT safeguards agreement was made effective in Japan in December 1977, the agency had already been conducting extensive safeguards inspections in Japan under the INFCIRC/66/Rev.2-type safeguards agreement. In FY 1976, i.e., from April 1976 to March 1977, the IAEA conducted its inspections in Japan with 232 person days of inspection (PDIs) in total, at seventeen power reactors, six conversion/fuel fabrication plants, twenty-four RRCAs, sixteen R&D facilities, one reprocessing plant, and sixty-two LOFs.

The experience gained in applying INFCIRC/66 safeguards proved to be invaluable and did much to equip the IAEA for the challenging task that lay ahead, namely to verify the obligation accepted by non-nuclear-weapon states under the NPT to place virtually all their nuclear material under IAEA safeguards.[5]

Establishment of Japanese SSAC under the NPT Safeguards Agreement and Additional Protocol

The safeguards agreement between Japan and the IAEA, or INFCIRC/255,[6] went into effect in December 1977 and the relevant law, Nuclear Regulation Law, and its regulations were revised accordingly to establish the Japanese State System of Accounting and Control (SSAC) for facilitating the provisions of INFCIRC/255. Major features were:

- Making the operator's recording and reporting system for nuclear material accountancy conform to those required under INFCIRC/255;
- Authorizing the IAEA inspectors access to nuclear facilities, with the escorting of Japanese national safeguards inspectors, in order to conduct relevant verification activities;
- Requiring facility operators to submit to the competent government agency[7] their "nuclear materials accounting and control procedures" for government authorization, in order to accommodate the various provisions stipulated in their specific facility attachment;
- Legally recognizing the Nuclear Material Control Center (NMCC) as the "authorized information treatment organization" to handle nuclear materials accounting reports submitted to the government by the facility operators, and transmit them in electronic forms to the IAEA.[8]

Japan is the first country, among those with a fully developed fuel cycle, to ratify the Additional Protocol (AP), which went into effect on December 16, 1999. She initiated several initiatives for its early entry into force and smooth implementation.[9] They include:

- Accommodating the requirements of the AP, *inter alia,* to collect and provide necessary information to the agency on Annex I;
- Authorizing the IAEA inspectors to make a complementary access to the locations as provided by the AP with the escort of Japanese government representatives;
- Designating NMCC as the official entity to perform certain national safeguards inspections on behalf of the Japanese government in anticipation of further closer cooperation between the Japanese SSAC and the IAEA.

In June 2004, Mohamed ElBaradei, the Director General of the IAEA, reported to the Board of Governers meeting that the Secretariat was able to reach all conclusions needed for the implementation of IS (integrated safeguards) in Japan, the state with the largest nuclear program subject to agency safeguards. IS was introduced in Japan in mid-September 2004, in a phased manner, initially with light water reactors (LWRs) without MOX, RRCAs, and spent fuel storage facilities. Later, since January 2005, IS is being implemented in LWRs with MOX and LEU fuel fabrication plants.

Collaborations Between Japan and the Agency in the Past

With a view toward achieving and facilitating efficient and effective IAEA safeguards under NPT, Japan has been actively involved in various activities for promoting close cooperation between her SSAC and the IAEA. The followings are some examples of such collaborations in safeguards implementation to date:

- **JCM:** In accordance with Article 18 of the Protocol to INFCIRC/255, JCMs (Joint Committee Meetings) have been established and are held annually. The representatives of Japan and the agency consider not only issues arising from the implementation of INFCIRC/255 and its protocol in order to reach mutually agreeable solutions, but also examine the development of safeguards methods and techniques with a view to further benefiting from the result of new technological developments. As substructures of JCMs, the plenary and the relevant working groups meet several times per year to address specific issues at the technical and professional level;
- **TRO:** With the cooperation of the Japanese government, the agency established in July 1984 and has been operating the Tokyo Regional Office (TRO) for the efficient and effective implementation of agency safeguards in the Far East region. The number of inspectors resident at TRO has increased from two to twenty-three over the last two decades;
- **JASPAS:** In 1981 Japan established JASPAS (Japan Support Program for Agency Safeguards) to assist the IAEA in the area of safeguards R&D as well as to provide CFEs (cost-free experts), training of inspectors and financial support. There have been sixty-six tasks that are completed and fourteen tasks are currently in progress, covering such areas as a) design of safeguards systems and approaches, b) collection, processing and evaluation of safeguards data, c) measurement methods and techniques, d) containment and surveillance technology, and e) provision of CFEs and training;
- **TASTEX, HSP, and LASCAR:** Japan has been actively participating in such international/multilateral safeguards projects as TASTEX (Tokai Advanced Safeguards Technology Exercise), HSP (Hexapartite Safeguards Project), and LASCAR (Large Scale Reprocessing Plant Safeguards Project) in order to develop/demonstrate effective and efficient safeguards technologies for the Tokai Reprocessing Plant (TRP), to develop effective and efficient safeguards approaches for a centrifuge enrichment facility and a large scale commercial reprocessing facility, respectively;
- **AP Implementation Trials and IS Rehearsals:** As a part of JASPAS, the Japanese government offered the IAEA a series of implementation trials of AP prior to its entry-into-force. The trial was conducted between March 1998 and December 1999 at two large research centers to cover the measures contained in the Model AP, including complemen-

tary access and managed access in order to provide relevant implementation experience for the IAEA, facility operators, state authorities, and eventually other states.[9] With the objectives similar to AP implementation trial, Japan provided the agency with the opportunity and financial support to conduct a series of IS rehearsals in 2003 and 2004, focusing on the implementation of random interim inspections (RIIs); [10]

- **Safeguards Approaches:** Japan and the agency have been collaborating extensively in establishing facility-specific safeguards approaches as well as generic safeguards approaches including IS approaches, site approaches, and SLA (state-level approach).
- **Facility Operators Cooperation:** The Japanese government has been successful in gaining the cooperation of facility operators to use their facilities as a test bed for advanced safeguards equipment and methodologies as well as to provide some of their equipment/instrumentation for safeguards use with necessary authentication requirements in order to facilitate agency's independent verification;
- **SIR Seminars:** In order to improve inspection goal attainment in Japanese facilities, NMCC has been organizing since 1985 "SIR Seminars" for facility operators, with the cooperation of the Science and Technology Agency (STA) and the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) and the agency, to better understand the causes of non-attainment of inspection goals at their facilities, if any, and to take remedial measures to prevent recurrence as appropriate.

Current Status of Collaborations between Japan and the Agency

Taking into account the increasing importance of cooperation of SSACs with the IAEA, the agency and Japanese SSAC are currently engaged in various areas of collaborations. Their best examples are the JNFL (Japan Nuclear Fuel Limited) Projects and the joint inspection use of safeguards equipment.

JNFL Projects

Two large-scale commercial fuel-cycle facilities are either under commissioning or in an advanced design stage. One is RRP (Rokkasho Reprocessing Plant) and the other is JNFL MOX Fabrication Plant (J-MOX). Both pose significant challenges in devising an effective and efficient safeguards approach, due to the amount of sensitive nuclear materials involved.

The construction of RRP started in 1993 and it is expected to go into full operation in November 2007. It has large throughput (800 t-U/year), having continuous operation campaigns for a prolonged time period, with fully automated and remote operation that prevents direct inspectors' access to strategic points. As recognized in LASCAR, new/advanced verification techniques and methods are to be incorporated, such as near-real-time accountancy (NRTA), solution monitoring (S/M) and other advanced C/S systems, as well as automatic inspection data collection systems.

The IAEA established the JNFL project to review and establish the effective and efficient safeguards approach for RRP and extensive consultations were made with the Japanese SSAC, namely JSGO (Safeguards Office, MEXT), NMCC, and JNFL, through the above-mentioned plenary and working group meetings under JCM. Advanced safeguards verification systems for joint-use by the agency and the Japanese SSAC have been approved and installed. Some of the above equipment are provided by the IAEA while, others are provided by the Japanese SSAC. Further, the agency provides the evaluation software for S/M. In addition, for the sake of timely analysis of chemical samples, On-Site Analytical Laboratory (OSL) has been constructed by JSGO with the cooperation of JNFL for common use by NMCC and the agency. It should be noted that early provision of DIQs (Design Inventory Questionnaire) on RRP facilitated timely DIV activities, with full cooperation of JNFL and JSGO.

The licensing of J-MOX is now underway, and it is expected that it will go into construction after obtaining its construction permit. It has the capacity of fabricating 130t-HM/year (up to 18 percent Pu concentration). Its operation is done with two-shifts/day and in full automation. New/advanced verification techniques and methods are inevitable, such as NRTA and integrated C/S. Early consultations are going on through JCM.

Joint Inspection Use of Safeguards Equipment

In 1990 the agency and the Japanese SSAC started the joint use of safeguards equipment and common procedures and its scope has successfully expanded to cover almost all NDA and C/S equipment authorized by the agency for its routine use in Japan.

As for NDA and C/S equipment installed in centrifuge enrichment, reprocessing and fast-breeder reactor facilities, most of the safeguards equipment was developed through JASPAS and is owned by the state or relevant facility operators. On the other hand, universal use NDA equipment, such as IMCG and IMCN, is provided almost equally by the agency and the state.

In principle, equipment that is owned by the IAEA and is used jointly with NMCC is portable NDA equipment, such as a power monitor for Japan Material Testing Reactor of JAERI (Japan Atomic Energy Research Institute) and a UF_6 header-pipe monitor for enrichment plants, as well as C/S equipment such as VACOSS and Cobra seals, and ALIS, DSOS, and ALIP video systems. On the other hand, facility owned unattended monitors are jointly used by the agency and NMCC, e.g., PCAS (Plutonium Canister Assay System), WCAS (Waste Crate Assay System), and MAGB (Material Accountancy Glove Box System) at PFPF (Pu Fuel Production Facility) for the measurement of Pu in canisters, waste drums and in-process inventory of a glove box. A portable uranium hold-up monitor owned by JNFL at REP (Rokkasho Enrichment Plant) is also another example in this category.

Exploring Potential Areas for Enhanced Collaborations

Growing Importance of Cooperation Between IAEA and SSACs

Cooperation with SSACs has been recognized from the outset of IAEA safeguards as a key element of effective and efficient safeguards. While the agency must be able to reach independent conclusions and therefore effectiveness should be the predominant consideration, increased cooperation can significantly increase the efficiency of safeguards implementation, and more can be done in this regard. This is recognized further in the development of IS and also in SAGSI's review of safeguards criteria. Cooperation with a SSAC is an important element of IS approaches for generic facility types and in the design of an SLA. In its review of agency's safeguards criteria, SAGSI also pointed out as one of its "major findings" that "achieving efficiencies in safeguards implementation is not only a matter for the agency—greater cooperation between the agency and state is required." [11]

In this context, the IAEA developed guidelines with a view toward identifying the potential areas for increased cooperation with SSACs, such as the timely provision of high-quality data by a SSAC necessary to support new safeguards approaches and the carrying out of joint activities.[12] The new partnership approach (NPA) between the agency and EURATOM served a good model of such cooperation.

Against this background, the agency made in 2003 a proposal to the Japanese government to jointly review the modality of its cooperation with the Japanese SSAC, and to see if the more cooperation is possible. This resulted in the establishment of the task force group (TFG) for enhanced cooperation (EC) under JCM in order to carry out this review.[13]

Review of Task Force Group

TFG reviewed the practical partnership under traditional safeguards as well as under IS, covering different categories of cooperation, i.e., enabling activities, joint inspection activities, and SSAC inspections activities as follows:

- **Enabling Activities:** They are comprised of activities carried out by the SSAC/operator that have the objective of enabling the IAEA to meet its mandate in an efficient and effective manner. This can involve a wide variety of activities but certainly includes advance reporting, assuring the quality of accountancy and measurement systems, assuring that nuclear material is available for verification and presented in a way that facilitates the IAEA verification activities;
- **Joint Inspection Activities:** Sharing of activities is done in order that both sides gain efficiencies. This includes such things as shared procurement of safeguards equipment, joint use of containment/surveillance and NDA equipment, joint review and evaluation of C/S, R&D on development of the C/S and NDA systems for safeguards applications (e.g., ACVD), joint training programs and joint conduct of inspections;
- **SSAC Inspection Activities:**[14] In this category, the IAEA under appropriate circumstances would use the results ("findings") of the SSAC inspection activities in place of some of its own activities in drawing safeguards conclusions. These would require necessary arrangements such as new procedures, training of state inspectors and technical preparation, e.g., authentication and tamper proofing of NDA and C/S equipment.

In each category of cooperation activities, TFG identified the activities that were being conducted routinely already (enabling activities), that should be expanded further (joint inspection activities), and that should be further explored (SSAC inspection activities). TFG concluded that, in order to gain further efficiency, the joint inspection activities should be implemented on the basis of "one-job-one-person" principle with appropriate quality control (QC) measures that are required for the IAEA to make use of the measurement results by an SSAC inspector for drawing independent conclusions. TFG made preliminary estimation of PDI requirements and concluded that introduction of EC would result in significant reductions: 21 percent reduction from the prevailing safeguards scheme in 2003. TFG considered that the EC would also bring a series of benefits to the operator such as: a) less intrusion for the operation (e.g., due to less inspection activities, if one-job-one-person principle is implemented), b) reduced time and effort spent by the operator for safeguards activities, and c) common inspection procedures and arrangements, thus minimizing conflicting demands by the two Inspectorates.

In order to assure the IAEA's capability of drawing its independent safeguards conclusions, TFG identified some preparatory measures that are required for implementing EC, such as: a) assuring the SSAC's technical competence level, b) authentication and installations of additional C/S and NDA equipment; c) arrangements on enhanced cooperation/use of all attended NDA stations, d) quality control mechanism on all EC activities; and e) creation of joint documentation/report formats on all EC activities (e.g., NDA, DA, C/S, book audit, etc.).

TFG made the following recommendations to the plenary meeting of JCM in December 2003:

- It is feasible to implement the full scope of EC with SSAC in Japan;
- The current joint-use activities should continue and be further elaborated as a base for full EC implementation;
- The necessary preparations to implement EC as identified above should be initiated;
- The detailed and specific EC approaches for individual type of facilities with cost benefit analysis are to be elaborated at the respective WG level;
- The rehearsals of full EC could be conducted at selected facilities to evaluate its effectiveness and efficiency.

Future Directions

When the TFG's recommendations were made, both the IAEA and the Japanese SSAC were faced with the urgent task of preparing for the transfer from traditional safeguards to IS in Japan that was approaching the final phase. Therefore, it was decided to defer the final decision on the recommendations of TFG to later dates, and devote limited resources of both sides to the development and the implementation of IS in Japan.

Since IS was introduced in a phased manner in mid-September 2004, the IAEA and the Japanese SSAC have been occupied extensively with further extending the application of IS to other types of nuclear facilities, *inter alia,* those with nuclear materials of more strategic value, including the establishment of a site approach. However, it is hoped that the situation may allow in the near future the Japanese SSAC and the agency to revisit the concept of EC in order to achieve more effective and efficient safeguards in Japan, by reflecting the major changes relevant to collaborations that have occurred since 2003 when the EC concept was reviewed by JCM, especially the experience of IS implementation.

Kaoru Naito is a graduate of University of Tokyo, with 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 has worked primarily in the area of nuclear safety and safeguards regulations. He has also served with the IAEA twice, for seven years 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 IAEA for nine years until the end of 2006. Currently he is a special assistant to the Minister of MEXT.

Nobuhiro Muroya is a graduate of Tokyo Institute of Technology, with a bachelor's degree in fluid dynamics. Currently he is the director of safeguards office, MEXT, in charge of implementing national safeguards, controlling the Japanese SSAC, and managing the day-to-day business with the IAEA for its safeguards implementation in the country. His experience in the international scenes includes working for more than three years each at the OECD as a senior staff member and the Japanese Embassy in France.

Notes

1. Naito, K. 2006. Japan's Nuclear Nonproliferation Commitment Manifested in "Framework for Nuclear Energy Policy," *Proceedings of the 47th Annual Meeting of the Institute of Nuclear Materials Management.*
2. Fischer, D. 1997. *History of the International Atomic Energy Agency, The First Forty Years,* IAEA, Vienna.
3. The early safeguards system set forth in INFCIRC/26 covered only the small research and experimental reactors of that time. Then the agency was able to reach agreement for the first set of safeguards measures for reactors of all sizes as set forth in INFCIRC/66, and, subsequently, for reprocessing plants in INFCIRC/66/Rev.1 and for fuel fabrication plants in INFCIRC/66/Rev.2.
4. They were Japan Power Demonstration Reactor (JPDR), JRR-2, Aqueous Homogeneous Reactor (AHR), Ozenji Critical Facility (OCF), NAIG Critical Assembly (NCA), and UTR-KINKI.
5. Fischer, D. 1997. *History of the International Atomic Energy Agency, The First Forty Years, IAEA,* Vienna.
6. Similar to EURATOM's NPT safeguards agreement with the IAEA (INFCIRC/193), INFCIRC/255 has its own protocol, where it is stipulated to the effect that Japan will establish and maintain its SSAC and that the IAEA will implement its verification activities through the observation of the inspection activities carried out by Japanese inspectors, provided that the SSAC of Japan achieves and maintains a degree of functional independence and technical effectiveness equivalent to that of EURATOM.
7. It was STA (Science and Technology Agency) at that time and is currently MEXT (Ministry of Education, Culture, Sports, Science, and Technology) after government reform in 2001.
8. In addition, NMCC was tasked to operate Tokai Safeguards Analytical Laboratory to analyze safeguards samples taken by the national inspectors in Japanese bulk handling facilities, as well as to carry out calibration and adjustment of national safeguards instruments, examine surveillance records and seals integrity, and conduct MUF analyses of selected nuclear facilities.
9. Naito, K., and K. Saeki. 2004. The Additional Protocol and the Road to Integrated Safeguards—Japan's Experience, *Proceedings of the 45th Annual Meeting of the Institute of Nuclear Materials Management.*
10. Naito, K., T. Ogawa, and T. Osabe. 2001. Progress Toward the Establishment of Integrated Safeguards in Japan, *Proceedings of the 42nd Annual Meeting of the Institute of Nuclear Materials Management.*
11. Report of SAGSI's Review of the Safeguards Criteria, SAR-42, 28 May 2004.
12. The IAEA has developed guidelines, "The Role of SSACs in Integrated Safeguards" (Rev.1. dated April 4, 2002), with a view to identifying the potential areas for increased cooperation with SSACs, classifying them into three levels: i) enabling level, ii) joint activity level and iii) SSAC inspection level. However, SAGSI is of the view that the activities that might be performed by the SSAC as part of cooperation with the agency fall in a continuum and that, rather than addressing the "level" of cooperation, it is more useful to focus on the activities themselves.

13. K. Naito. 2005. Enhanced Cooperation Between Agency and Japanese SSAC, *Proceedings of the 5th Joint INMM/ESARDA Workshop.*
14. Article 3 of INFCIRC/255 stipulates that the "IAEA, in its verification, shall take due account of the technical effectiveness of the National System." The *findings* of the SSAC, as referred in Article 3 (c) of INFCIRC/255, could be extended to include the results from inspection carried out by the state authority. Further, Article 4 of the INFCIRC/255 provides that "the government of Japan and the agency shall cooperate to facilitate the implementation of safeguards provided for in this agreement and shall avoid unnecessary duplication of their activities." Therefore, there is a sufficient legal framework for this level of enhanced cooperation, even though this has never been implemented in Japan. See also Note 6 above.

Safeguards Developments and Challenges in the ROK During the Last Fifty Years

Young-Myung Choi and Hosik Yoo
Korea Institute of Nuclear Nonproliferation and Control
Daejeon, Republic of Korea

Abstract

The Republic of Korea (ROK) joined the International Atomic Energy Agency (IAEA) in 1957 and ratified the Treaty on the Nonproliferation of Nuclear Weapons in 1975. Since then, the ROK has followed all the requirements established by the IAEA related to the State System of Accounting for and Control of nuclear materials. In 1997, national inspections at nuclear facilities were initiated independently, yet concurrently with IAEA inspections. Using remote monitoring technology and state's system utilization, enhanced cooperation on light-water reactors (LWRs) between the ROK and the IAEA has been implemented since 2002. In addition to the LWRs, discussion on the enhanced cooperation of the OLR reactor is underway. These new approaches are expected to reduce the IAEA's inspection effort significantly.

The ROK has also made efforts to develop equipment for safeguards inspection such as the spent CANDU fuel verifier, the Optical Fiber Scintillatorm and the Neutron Fingerprinting System. In order to enhance the transparency of nuclear activities, the ROK signed the Additional Protocol (AP) in June 1999 and ratified it in February 2004. As soon as entering the AP into force, the ROK started a discussion with the IAEA to apply the integrated safeguards scheme. The working group for the IS scheme was organized to design the integrated safeguards for all nuclear facilities in 2005. The measures for the integrated safeguards are different depending on the nuclear facility. At a working group meeting, IS schemes were developed for LWR, OLR, FFP, and RRCA. Most of the important issues were solved at the working group meetings, and it is expected that the ROK would be under the IS scheme by 2008.

Nuclear confidence building among neighboring countries can be achieved with patience, effort, and understanding. A regional cooperation scenario is presented based on the sprit of mutual confidence.

Introduction

The Republic of Korea (ROK) became a member state of the International Atomic Energy Agency (IAEA) in 1957. The first noteworthy encounter related to safeguards came in 1968. At that time, the ROK concluded the trilateral ROK-United States-IAEA safeguards agreement as the TRIGA Mark II, the first research reactor in the ROK, was introduced. Later, the ROK ratified the Treaty on the Nonproliferation of Nuclear Weapons (NPT) in April 1975. The State System of Accounting for and Control of nuclear materials (SSAC) was established after the safeguards agreement came into effect in 1975. As a result of these safeguards agreements, two research reactors, TRIGA Mark II and III, were the first nuclear facilities in the ROK to which the IAEA safeguards were applied. Since then, the ROK has been submitting official reports to the IAEA, while the IAEA performs verification activities such as safeguards inspection.

As results of government policy to steadily promote nuclear energy and development, thirty-five facilities are currently under the IAEA safeguards. The ROK signed the Additional Protocol in 1999. In 2004, the ROK ratified it and completed its initial declaration.

In the ROK, twenty nuclear power plants are in operation (sixteen PWRs and four CANDUs). The ROK started its nuclear power industry in 1978 witht the opening of Kori-1. In 2006, around 40 percent of the country's electricity is generated by these nuclear power plants. With this active nuclear power program, the ROK ranks sixth in the world in terms of nuclear power generation capacity.

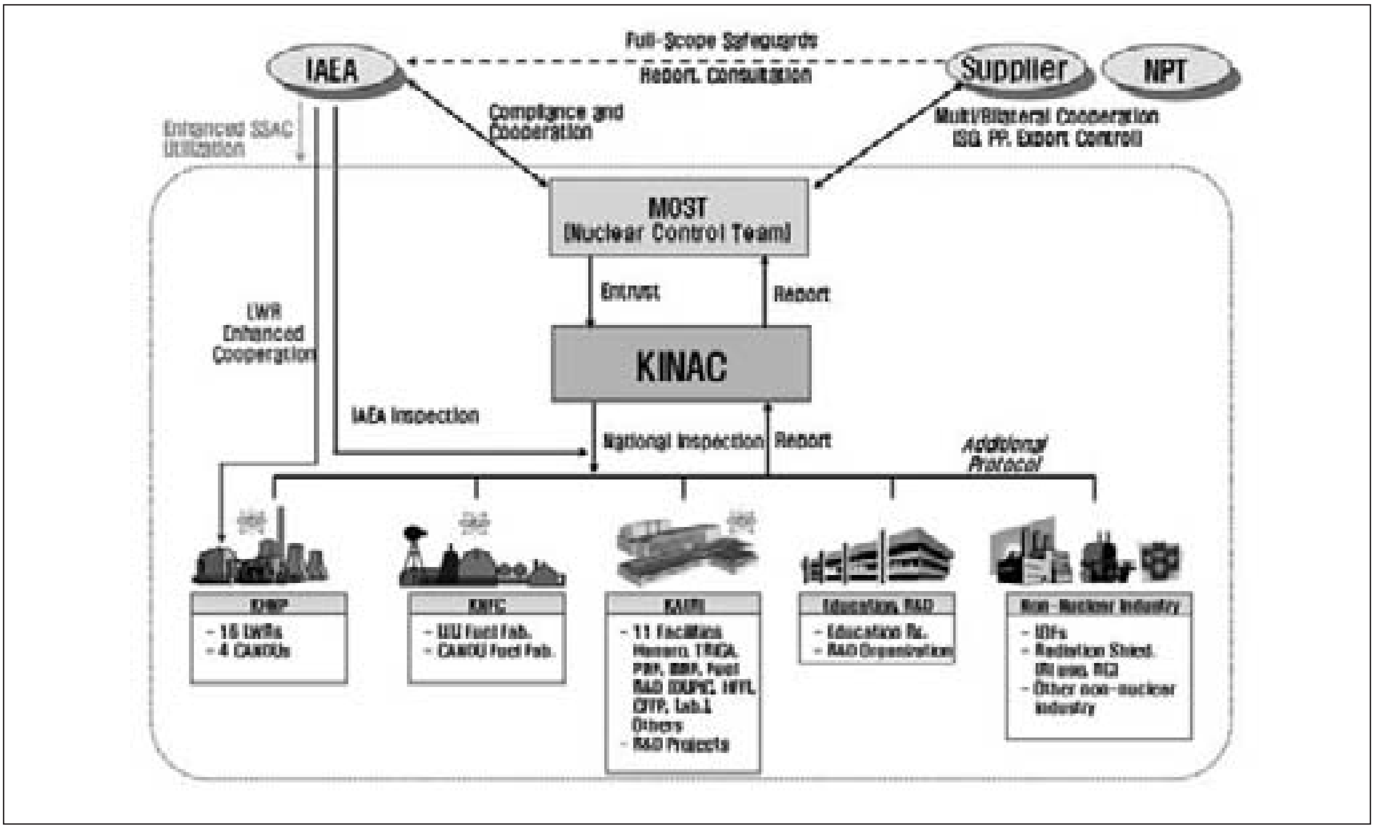
Other than nuclear power plants, there are commercial nuclear fuel fabrication plants, a critical assembly facility, and the HANARO research reactor, as well as another ten nuclear R&D facilities. The HANARO is a research reactor that reached criticality in 1995 and is used for fuel and material testing, radioisotope production for medical and industrial use, and for neutron beam application studies. With active nuclear R&D projects outlined by Korea's mid- and long-term R&D programs, nuclear-related facilities will continue to increase in numbers.

Table 1 shows the variation of the number of facilities and the person days of inspection (PDIs) for both the national and the IAEA safeguards inspections during the last ten years. The IAEA's onsite inspection was significantly reduced in 2002 due to the enhanced cooperation on LWRs, but it was increased again drastically in 2005 because of the transfer campaign for CANDU spent fuels to dry storage.

Table 1. Number of facility and PDIs for national and IAEA inspection

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
No. of Facilities	24	27	32	32	33	34	35	35	35	35
National Inspection On (PDIs)	59	238	394	315	329	314	353	266	592	580
IAEA Inspections On (PDIs)	267	360	439	351	377	310	313	263	519	494

Figure 1. SSAC structure in ROK



Korean SSAC

Historical Background and Legal Basis

Korean SSAC was established at the Ministry of Science and Technology (MOST), immediately after the Comprehensive Safeguards Agreement was entered into force in 1975. MOST designated the TCNC (Technology Center of Nuclear Control), which was established in 1994 at KAERI (Korea Atomic Energy Research Institute), as the formal technical body for national safeguards implementation. The Nuclear International Cooperation Division was responsible for national inspections until 2004. The Nuclear Control Team was established in 2005 as an authoritative organization for safeguards implementation at MOST. The TCNC changed its name to KINAC (Korea Institute of Nuclear Nonproliferation and Control) through the NNCA (National Nuclear Management & Control Agency). KINAC was established in June 2006 to enhance the independence of the SSAC with the mission of developing safeguards technology and to assist the government technically. A national inspection system was introduced in 1997 as an active measure to control nuclear material and facilities, to respond to international obligations, and to ensure the international transparency and credibility of nuclear activities (Figure 1). From the second half of 1997, national inspections have been initiated at seven nuclear facilities in Korea, representing each nuclear facility type and location on a test basis. In 1998, national inspections were expanded to thirteen nuclear facilities. From 1999, national inspections have been carried out at all nuclear facilities. The national inspections are performed according to the national inspection criteria and procedures, which are similar to the IAEA's safeguards criteria. Instead of using surveillance devices of the IAEA, direct verification of nuclear material and seals were used in national inspection until 2001. After concluding the enhanced cooperation scheme between the ROK and the IAEA in 2001, both parties began to share data about surveillance and seals from PWRs since 2002. In 2006, national inspections were carried out successfully at thirty-five nuclear facilities. Most of the national inspections were performed concurrently with the IAEA inspections to reduce the burden of facility operators.

The national inspections are performed according to the Atomic Energy Act that was amended in December 1994 and entered into force in January 1995. According to the act:

- Article 16 (Inspection): The nuclear power reactor installer shall be inspected by MOST, regarding installation of nuclear power reactors and related facilities, and accounting and control of nuclear materials in accordance with the provisions of the Presidential Decree.

In July 1996, four ministerial notices of MOST, including the provision that specified the report on the special nuclear material, went into effect and were amended once in 2004 to implement the provisions of the Atomic Energy Act and to provide detailed requirements and guidelines on the Additional Protocol. The scope of national inspections specified in the notice is as follows:

- Measurement of the records coupled with nuclear material accountancy kept by the operator
- Measurement of all nuclear material subject to safeguards
- Verification of the functioning and calibration of instruments and other measuring and control equipment at the facility
- Application and utilization of C/S measures
- Other necessary measures for safeguards implementation including sample taking for destructive analysis.

Features of National Inspection

MOST performs inspections regarding accountancy and control of nuclear materials. The details of inspections regarding frequency, methods, accountancy, and control are provided in the notices of MOST. If the inspection results confirm that a facility is operated in conformity with its own accountancy and control program, it is deemed to have passed the inspection.

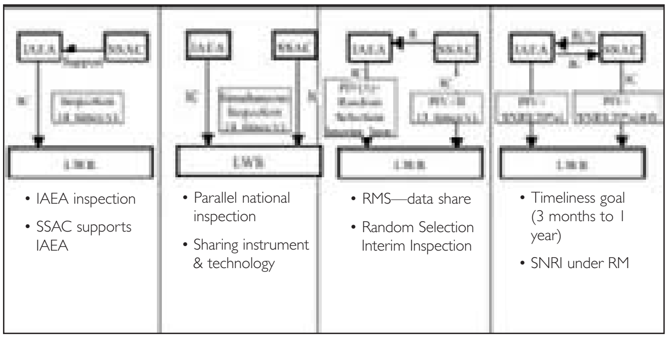
The frequency of national inspection is dependent on the inspection type. The routine inspections serving timely detection purposes are normally carried out every three months. However, the period between two consecutive inspections may be changed based upon the characteristics and size of a facility, and the type of nuclear material in a facility. The physical inventory verification (PIV) is performed once per calendar year, where the period between two consecutive PIVs does not exceed fourteen months. Ad hoc inspections and special inspections can be carried out anytime dependent upon the purpose of their inspections. Design information verification is carried out before the startup of the facility and is also performed annually during a PIV.

In order to conduct inspections effectively and efficiently, procurement/development of adequate inspection equipment is necessary since the types of nuclear materials are facility dependent. The kinds of safeguards equipment can be categorized as nondestructive analysis (NDA) equipment, destructive analysis (DA) equipment, and containment/surveillance (C/S) equipment. Some of the facility-dependent equipment used for national inspections include: the SCAV (spent CANDU fuel verifier), SCAI (spent CANDU fuel identifier), SCAD (spent CANDU fuel verifier in dry canister) for spent fuel verification at CANDU reactors. The verification equipment such as the SCAV, the SCAI, and the SCAD were developed by the ROK. Currently, various kinds of inspection equipment, except surveillance systems, are secured for national inspections and advanced equipment are being developed or purchased. Regarding sealing systems, *in situ* verifiable seals (TROVAN seal) are used for national inspections. User manuals and procedures as well as working papers are prepared for most of the frequently used inspection equipment.

Since 1978 when the Kori-1 began to operate, the methodology of the ROK's safeguards inspection for the LWR has been changed as shown in Figure 2. National inspections were initiated in 1997 and the IAEA's onsite inspection was reduced through enhanced cooperation. It is expected that the feature of the ROK's national inspection would be much different when the integrated safeguards come into effect.

Figure 2. Evolution of safeguards on LWRs in ROK

1978 – 1996	1997 – 2001	2002 – present	After IS
IAEA Inspection	Simultantous Inspection	Enhanced Cooperation	Integrated Safeguards



- IAEA inspection
- SSAC supports IAEA

- Parallel national inspection
- Sharing instrument & technology

- RMS—data share
- Random Selection Interim Inspection

- Timeliness goal (3 months to 1 year)
- SNRI under RM

Note: IC: Independent Conclusion, R: Report, SNRI: Short Notice Random Inspection, II: Interim Inspection

ROK-IAEA Enhanced Cooperation

Enhanced Cooperation for LWRs

LWR Enhanced Cooperation Arrangement

The ROK and the IAEA signed an MOU (memorandum of understanding), the International Atomic Energy Agency and the Ministry of Science and Technology of the Republic of Korea for an Enhanced Cooperation on Safeguards Implementation at Light Water Reactors in the ROK for LWR Enhanced Cooperation, in 2001 and implemented it starting in 2002. The MOU has an annex (Enhanced Cooperation Arrangements Between the IAEA and the ROK SSAC on the Implementation of Safeguards at LWRs in the ROK). All details for the enhanced cooperation implementation are specified in the Annex. Basic concepts and schemes are as follows:

- One PIV annually
- Up to four interim inspections annually for timely detection purposes and pre- and post-PIV activities
- Inspections as necessary for verification of shipments and receipts of spent fuel
- Inspections relating to the zone approach for LEU in Korea (These inspections will also provide confirmation of the absence of borrowing.)
- Inspections for follow-up activities, if any

The basic concepts of the LWR enhanced cooperation scheme are that the ROK SSAC participates in all scheduled inspections for LWRs while the IAEA performs the annual PIV/post-PIV inspections and other inspections as deemed necessary by the IAEA. To ensure that the IAEA is able to draw timely independent conclusions, a remote data transmission scheme has been adopted as follows:

- All possible removal routes in all LWRs are under continuous C/S measures
- All C/S data are authenticated and remotely transmitted to the IAEA headquarters in Vienna in parallel to the ROK SSAC in an encrypted form through VPN (Virtual Private Network)
- Operating and accounting records necessary for the IAEA's C/S review are encrypted and submitted electronically to the IAEA by the ROK SSAC on a monthly basis.

Implementation of LWR Enhanced Cooperation

Since the LWR enhanced cooperation scheme is based on Remote Data Transmission (RDT) technology, it is very important to ensure the function and integrity of the RDT system. In 1998, a field trial for RM (remote monitoring) was first conducted at a PWR. The ROK and the IAEA concluded to use RM to reduce inspection efforts on both sides after years of testing. Remote monitoring systems were steadily installed in all LWRs from 1999 to 2001 with the member state support program (MSSP). All possible removal routes in all LWRs are under continuous containment. Cameras are used to monitor equipment hatches and spent fuel storage ponds and VACOSS seals at equipment hatches and canal gates. All surveillance and seal data of LWRs are authenticated and remotely transmitted electronically to IAEA headquarters in Vienna in an encrypted form through VPN in parallel to KINAC, Daejeon. Before 2004, the C/S data was transferred to the IAEA through a telephone line. Transmission by telephone line has a disadvantage in terms of cost. A VPN that was deployed on a shared infrastructure (such as the Internet) with the same policies and performance as a private network was considered. The study on the VPN was carried out through the MSSP, "Implementation of VPN for Remote Monitoring." As a result of MSSP, VPN was installed at all PWR plants in April 2004. VPNs add security to Internet communication by making use of encryption and data authentication. Encryption technology converts data from a readable format to a cipher text that only the intended recipient can decipher. Data authentication technology enables us to verify that the data has not been altered, substituted, or removed. It also provides verification of the identity of the information source. A VPN also has the advantage in flexibility to allow more connection options than direct dial and a higher connection reliability. Cost savings is also seen.

Enhanced Cooperation for CANDU Reactors

Remote Monitoring and Interim Inspections at the Reactor

Based on successful implementation of the LWR enhanced cooperation scheme, application of such a scheme to CANDU reactors is under discussion. The Enhanced Cooperation Scheme, which would apply to all four Wolsong CANDU reactors in the ROK, would be based on the following:

- The SSAC is to conduct all interim inspections; the IAEA will participate in interim inspections randomly under an unannounced inspection regime.
- When the SSAC performs an interim inspection without the presence of IAEA inspectors, the SSAC will send the IAEA inspection results together with relevant working papers in accordance with IAEA standards.
- The IAEA will always perform PIV inspections and DIVs.
- Continuity of Knowledge is to be maintained by an interlinked NDA surveillance for the core fuel and the flow by the Core Discharge Monitor and Bundle Counters with the DMOS (Digital Multi-Camera Optical Surveillance) system for the spent fuel ponds.
- The IAEA will draw independent conclusions with respect to NDA and surveillance through its review of NDA & C/S data transmitted from the CANDUs (through the hub station installed at the Wolsong site to the IAEA headquarters in Vienna).
- The IAEA will perform the NDA and C/S data review and its evaluation based on the information supplied by the ROK in an agreed format.

The IAEA proposed the following scheme for implementing enhanced cooperation at CANDU reactors in the ROK.

Phase I: Implementation of Remote State of Health Over VPN

Remote state of health will involve the establishment of a VPN link to each DMOS unit at Wolsong in order to perform daily checks on the power supply and confirm that each unit is functioning properly. It will not involve the retrieval of any surveillance images.

Phase II: Implementation of Remote DMOS and VIFM Data Transfer

The IAEA proposes to begin the retrieval of images and bundle counter data when the technology is ready. The IAEA will consult with the ROK before implementing this phase.

Phase III: Implementation of Enhanced Cooperation for CANDUs

Implementation of Phase III will require the IAEA and the ROK to agree on the details of:

- Data sharing arrangements
- Provision of accounting and operational data
- A new inspection regime (quarterly interim and short notice inspections)

A rehearsal of the above scheme was initiated in 2004 and Phase I & II was successfully conducted in 2006. Currently, the ROK and the IAEA are negotiating the implementation of Phase III.

Development of Streamlined Inspection Scheme for Transfer of CANDU Spent Fuel to Dry Storage

To provide the necessary space in the spent fuel ponds for continuing CANDU reactor discharges, spent fuels have to be transferred from the ponds to an on-site dry storage canister at the Wolsong NPP. Spent fuels have been transferred to canisters since 1993, and this will be continued for the next few decades. The IAEA currently verifies the transfer of spent fuel to dry storage canisters. The transfer campaign at four CANDU reactors require significant safeguards resources if the current approach, which relies heavily upon inspectors being present at the Wolsong site, is to continue.

In a continuous development for more efficient approaches to meet traditional safeguards, which would also be applicable for integrated safeguards in the future, the IAEA and the ROK are working together to develop and test a new safeguards scheme that depends less upon the IAEA inspector's presence and efforts.

The IAEA currently verifies the transfer of the spent fuel according to the safeguards obligations by means of the presence of an IAEA inspector during the entire transfer campaign period. With respect to the drastically increasing safeguards PDI and its effort, the IAEA and the ROK jointly developed a new approach for safeguarding spent fuel transfer. The main tasks are the mailbox approach for *in situ* verification, maintenance of the continuity of knowledge (COK) by a radiation tracking and surveillance camera, and an administrative arrangement and inspection procedure for unannounced and short notice random inspections. The new scheme should also ensure that the IAEA can complete all verification activities required between the spent fuel pond and dry storage without causing delays in the operator's schedule.

R&D Activities for Maintaining Continuity-of-Knowledge

The ROK has conducted various R&D projects related to nuclear material verification. These projects have focused on developing equipment and systems that increase the effectiveness and efficiency of safeguarding. Some of them are performed through the collaboration with the IAEA. The following are R&D activities that are currently being carried out:

Verification System for CANDU Spent Fuel Bundles at Pond Area

This system has been developed for verification of CANDU spent fuel bundles stored in bay areas hidden by funnel structure for IAEA ultrasonic seal at the Wolsong NPP. A small optical fiber scintillator is positioned between bundles in trays, and measures the gross gamma intensity as a function of vertical position by scanning the storage stack. This system was demonstrated in 2005 with the attendance of an IAEA specialist at the Wolsong site. Currently, the MSSP is being performed to apply the system for item counting of CANDU bundles in IAEA inspections. The final test was performed in February 2007 for IAEA authentication.

Neutron Fingerprinting System for CANDU Silo

In order to measure the neutron profile for newly filled baskets in canisters after the completion of transfer campaign, a neutron fingerprinting system, which is composed of a neutron detector and a scanning device, is being developed. BF_3 and He-3 neutron detectors with various gas pressures are designed for use in reverification tubes. The field test was performed at the end of 2006.

Installation of DNAA Facility in HANARO

Delayed neutron activation analysis (DNAA) is a method for detection and qualifying of fissile material in various types of samples by delayed neutron counting. It consists of a pneumatic transfer tube system and a neutron detector assembly with signal processing equipment. The installation of the DNAA facility at HANARO was completed and a performance test was conducted in early 2007.

Efforts for Strengthening SSAC

Implementation of the Additional Protocol (AP)

After signing the AP in June 1999, the ROK identified the area for preparation of AP Implementation and started to amend the law. The Atomic Energy Act was revised to reflect the pertinent articles of the AP. The AP entered into force in February 2004, and a task force was organized to implement initial declarations. In order to make facility operators and relevant officials familiar with the AP and its obligations, including guidelines for initial declarations, the government provided extensive education and training. All facility operators, including universities, were required to submit their initial reports, which were then compiled by the government, reviewed, and sent to the IAEA in August 2004. The reports consist of 924 entries from sixteen facilities.

The declaration should be updated every year before May 15. The IAEA has performed complementary accesses to many facilities such as power reactors, research facilities, fuel fabrication plants, and universities since the initial declarations. On January 2, 2006, subsidiary arrangement of the AP, which includes many useful articles to effectively implement the AP, became effective.

Integrated Safeguards (IS)

The ROK started discussions with the IAEA for the application of integrated safeguards in March 2005. The ROK and the IAEA formed a joint working group to begin drafting integrated safeguards approaches for ROK facilities and sites, and to plan rehearsals of integrated safeguards random interim inspections. Up to now, five working group meetings have been held since the first meeting in the ROK in 2005. At the meetings, many topics were discussed, and progress was made on the topics such as: the introduction of a mailbox system and short notice inspections at the fuel fabrication facility, finalization of IS approaches for LWRs, CANDU reactors, RRCA, and site approaches for the research institutes. In 2006, rehearsals of IS random interim inspection was conducted for PWRs and fuel fabrication facility. It is expected that a broader conclusion would be reached soon and the ROK would go into IS in the near future.

Challenges—Regional Cooperation

Background

Regional cooperation for the peaceful use of nuclear energy and for nuclear safeguards stems from many political and historical reasons among nations in the region. Two regional organizations—Euratom and ABACC—are taking a leading role in cooperating with the IAEA to strengthen regional security and the NPT regime worldwide.

Regional cooperation has allowed region members to gradually gain confidence with one another. Asia-Pacific countries have suffered indescribable pains in political and military relations since the last part of nineteenth century. While Southeast Asian nations developed greater regional cooperation during the Cold War, Northeast Asian nations have been unable to do the same. Asia-Pacific countries that have developed peaceful nuclear energy programs have met the transparency requirements for nuclear energy use. This fact gives us a common interest in the peaceful application of nuclear energy, which could be developed for regional cooperation.

Principles and Steps for Regional Cooperation in Asia-Pacific Area

Regional cooperation requires nuclear controls as a prerequisite condition. In this sense, collaboration of nuclear controls in Asia-Pacific area could be developed under the following conditions. The three principles are as follows: First, active exchanges of persons and information among concerned nations help build mutual confidence. Second, non-military nuclear technologies should be shared. Third, gradual institutionalization and regular meetings shall be carried out for the construction of a multilateral inspection system. The three implementing steps are as follows: First, regional countries are to promote mutual or multilateral exchanges of experts, joint training courses, and common research projects for the peaceful uses of nuclear energy. Second, regional countries are to implement joint inspection and/or mutual inspection for the facilities of a common system. Third, regional countries are to establish and manage a regional system for accounting and control of nuclear materials (RSAC). This means that all the facilities, agreed among members, are to be available for access by the inspector of the RSAC. As a first step to regional cooperation, Korea, Japan, and Australia could initiate a common training course of safeguards under the auspices of the agency. The actual efforts of regional cooperation in safeguards training: KINAC-IAEA-NMCC and Japan-IAEA-Australia, could be merged into a regional training course, in which other regional countries in the Asia-Pacific area could be joined fully for the training. The control of nuclear energy and facilities could be applied in a different way according to the level of implementation on the Additional Protocol.

The regional countries could start their joint work by exchanging information and technologies. Cooperation should be based on safeguards information, common training, and diverse discussion for the institutionalization of regional collaboration. Regional countries must prepare an institutional unity to discuss fully the question of regional cooperation of safeguards for the peaceful uses of nuclear energy.

Conclusion

The ROK concluded the trilateral ROK-USA-IAEA safeguards agreement as TRIGA Mark II was introduced in 1968. It was the first practical activity related to safeguards since the ROK became a member state of the International Atomic Energy Agency (IAEA) in 1957. In 1975, the ROK ratified the NPT and established the State System of Accounting for and Control of nuclear materials (SSAC) after the safeguards agreement became effective. As a result of this full scope safeguards agreement, the IAEA safeguards were applied to TRIGA Mark II and III for the first time. The ROK adopted a national inspection system in 1997 as an active measure to maintain and secure its nuclear material and facilities, to respond to all international obligations, and to ensure the international transparency and credibility of its nuclear activities. Since then, national inspection has been performed for all the nuclear facilities, concurrently with IAEA inspections. The ROK and the IAEA closely cooperate in seeking possible new ways to create a more efficient and effective safeguards implementation. As a first step, enhanced cooperation for the LWRs, based on remote monitoring technology and the state's system utilization, was introduced and a MOU for implementation was signed in October 2001. As a result of this enhanced cooperation, the IAEA's on-site inspection time was significantly reduced. In addition to the enhanced cooperation, the ROK closely cooperate with the IAEA through the MSSP to develop the equipment for safeguarding. Several types of verification equipment such as SCAV, SCAI, and SCAD were developed and used for national safeguards. The enhanced cooperation scheme at LWRs turned out to be a great success with close communication and cooperation among facility operators, the ROK SSAC, and the IAEA. Based on this success, a new approach for the CANDU type reactors is being developed. With this new approach, effectiveness and efficiency will be improved. This new approach is considered to be an interim measure before an integrated safeguards approach. But it is expected that this new approach will have an equivalent effect on integrated safeguards and will be easily adaptable for IS applications in the future. The ROK has closely cooperated with the IAEA in applying the IS scheme since the AP was ratified in 2004. IS schemes were developed and most of the important issues were solved at the working group meetings. It is expected that the ROK would be under IS soon. All these efforts will enhance the transparency of nuclear related activities in the ROK.

The assurance of nuclear nonproliferation among neighboring countries can be achieved with patience, effort, and understanding. In order to facilitate regional cooperation, regional countries should work jointly to exchange information and technologies. Based on this, regional nations should prepare an institutional unity to discuss fully the question of regional cooperation of safeguards for the peaceful uses of nuclear energy.

Young-Myung Choi is a research fellow at the Korea Institute of Nuclear Nonproliferation and Control. He has a Ph.D. and M.S. in operations research from State University of New York at Stony Brook and a B.S. in industrial engineering from Seoul National University.

Hosik Yoo is a senior researcher at the Korea Institute of Nuclear Nonproliferation and Control. He has an M.S. and a B.S. in metallurgical engineering from Korea University.

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Cooperation on International Safeguards Between the IAEA and South Africa

Dietlieb L. Tillwick and Joseph L. Shayi
South African Nuclear Energy Corporation, Pelindaba, Pretoria, South Africa

Abstract

South Africa started cooperation with the International Atomic Energy Agency (IAEA) in the 1960s with facility-type agreements (INFCIRC/66) for the SAFARI-1 Research reactor and Koeberg Nuclear Power Station reactors. No further agreements were concluded until termination of the South African (SA) weapons program and ratification of the Nuclear Nonproliferation Treaty (NPT) in 1991. Thereafter intense cooperation ensued with the IAEA through signing of a comprehensive safeguards agreement (INFCIRC/153), preparation of the completeness report for nuclear material inventory and nuclear facilities; and implementation of the comprehensive safeguards agreement. Notably, at this early stage SA already granted access to IAEA inspectors to any facility at any location within SA in a fully cooperative and transparent manner.

SA has endeavored to strengthen the international safeguards regime through participation in various IAEA activities (e.g., MSSP, Program 93+2 and SAGSI), IAEA Board of Governors and General Conference; and field trials on environmental sampling and RMS. In 2002 the Additional Protocol (INFCIRC/540) entered into force. Through the IAEA support program quantification and verification of HEU/LEU in waste from the weapons program and other nuclear facilities was intensely pursued until the present day.

Working towards a more effective and efficient SSAC the SA safeguards system was ISO 9001 certified in 2003. Best practices of the SA SSAC were shared in an IAEA SSAC workshop and through the preparation of the IAEA Nuclear Materials Accounting Handbook. SA participates in voluntary reporting schemes such as import and export of nuclear materials. Further, SA fully cooperated with the IAEA in investigating the clandestine manufacture of enrichment plant components in SA destined for Libya.

On a regional basis SA in conjunction with the IAEA hosted a regional seminar to promote the conclusion of Additional Protocols by African states and an African regional workshop for SSACs. SA and the IAEA are evaluating and assessing the verification and control systems at SA borders of mineral ores containing uranium and metals (e.g., cobalt and copper) containing high levels of uranium as impurities.

SA historical nuclear capabilities are utilized in new technologies such as the pebble bed modular reactor project for which a new safeguards approach is being developed. Implementation of the IAEA state-level approach combined with the Annual Inspection Plan and transition to IS for SA poses specific challenges.

Introduction

South Africa (SA) and the International Atomic Energy Agency (IAEA) have some key relationships in particular in view of the unique position that South Africa holds as being the only member state that had developed a nuclear deterrent capability and voluntarily dismantled its nuclear devices before acceding to the NPT. In the IAEA's celebration of its fiftieth year of existence it would be appropriate to outline the special safeguards relationship that developed during the 1990s with South Africa and how it manifests itself in the transparent and cooperative relationship which exists presently.

Safeguards in South Africa Not Under NPT

In 1961 the South African Atomic Energy Board (AEB), which was established by an act of Parliament in 1948, began nuclear research and development at the Pelindaba Nuclear Research Center near Pretoria. In 1965 the first SA reactor SAFARI-1 which was supplied by the United States went critical. An agreement was reached between SA and the United States that the IAEA would apply safeguards at SAFARI-1 in terms of an INFCIRC/66 type agreement which was published as an IAEA document INFCIRC/98. This agreement was amended on various occasions and was finally published as INFCIRC/98/Mod.1 in 1977.

The next nuclear reactors were the two French supplied PWRs (900 MW each) at the Koeberg Nuclear Power Station (KNPS). In a trilateral arrangement with SA and France safeguards by the Agency was applied in terms of the facility-type agreement INFCIRC/66, which entered into force in 1977 as INFCIRC/244. During the construction of the PWR fuel manufacturing plant at Pelindaba a Hot Cell Complex (HCC) capable of handling irradiated PWR fuel pins from KNPS and other irradiated products from SAFARI-1 was built during the early 1980s. The INFCIRC/66 type agreement was applied to the HCC by listing it as a Category II inventory under the existing INFCIRC/98/Mod.1.

South Africa's Nuclear Weapons Program

The historical account of the nuclear weapons program[1,2] has been given but some of the pertinent points will be highlighted here for completeness. Mainly as a result of South Africa's internal racial policies and the geopolitical tensions developing in the Southern African region, South Africa experienced increasing international isolation and sanctions during the 1970s and 1980s. Some of these included the following:

- By the late 1970s SA's participation in the UN General Assembly and its agencies was suspended,
- The Security Council had imposed a mandatory weapons embargo and a voluntary oil embargo on SA,
- In 1977 SA was denied its designated seat on the Board of Governors of the IAEA and participation in the General Conference,
- HEU fuel supply for the SAFARI-1 reactor by the United States was terminated, and
- Delivery of enriched UF_6 for PWR fuel production for the two KNPS units also became problematic.

South Africa therefore felt itself compelled to enrich uranium, which it did in its own developed process, and manufacture fuel to ensure a guaranteed supply of fuel for the test and commercial reactors. A political decision was also taken to develop a limited nuclear deterrent capability. Nevertheless, throughout the whole period South Africa honored the two facility-type safeguards agreements in force, provided the required nuclear material accountancy data, and in an unhindered way permitted all other verification activities by the IAEA on the three reactors and the HCC. During the 1970s and 1980s South Africa fully complied with the facility-type safeguards agreements in place. All other nuclear facilities (e.g., HEU and LEU fuel cycle facilities and weapons program facilities) were not subject to safeguards since no safeguards agreement had been concluded nor was the NPT signed, which would have required the conclusion of a comprehensive safeguards agreement (CSA). In September 1987 the SA government first indicated in a press release that it hoped to be able soon to accede to the NPT. Nevertheless, in the late 1980s a nuclear material accounting and control system was established for SA nuclear facilities not under INFCIRC/66 safeguards.

SA realized in the late 1980s that the accession to the NPT would be beneficial for its international relations. The geopolitical tensions in the region had subsided and the nuclear deterrent capability was no longer seen as necessary. However, before acceding to the NPT and signing INFCIRC/153 type CSA with the IAEA, SA decided that all facilities used for the manufacture of nuclear explosive devices would be decommissioned, decontaminated, mothballed, or converted to peaceful commercial use; HEU nuclear material from devices melted down and stored; and technical drawings destroyed. This was accomplished by July 1991 when South Africa acceded to the NPT (except for the dismantling of the enrichment plant, which took up to eighteen months). In September 1991 SA signed the CSA (INFCIRC/394) and by the end of October 1991 submitted to the IAEA an initial report of the complete inventory of nuclear materials and facilities. This allowed SA to take up its seat in the General Conference of the IAEA and in 1993 to become a member of the Zangger Committee.

Formally the president of SA announced in March 1993 that SA had possessed and subsequently dismantled its nuclear deterrent capability.

Implementation of Safeguards in South Africa under NPT

In the period from signing the CSA to the change in government in April 1994 the IAEA pursued an intensive verification program and implementation of safeguards in SA followed. In November 1991 the IAEA sent a special training team to SA to assist the SSAC and nuclear facility operators with implementation of the safeguards agreement. This was followed up by a more detailed workshop on accounting and reporting in February 1992. South Africa's commitment through adherence to the NPT and implementation of the CSA was demonstrated by:

- The short period after acceding to the NPT within which the CSA and the initial declaration were signed and submitted.
- The subsidiary arrangements were in force by August 1992.
- Six facility attachments were in force in early 1993.
- Establishment of the legal framework through new legislation: (i) Nonproliferation of Weapons of Mass Destruction Act 87 (of 1993) and (ii) Nuclear Energy Act 131 (of 1993).

The IAEA proceeded with verification activities to determine the correctness and completeness of the initial declaration of nuclear materials and facilities. In order to perform this difficult task the IAEA inspectors had to go into the records of historical nuclear activities dating back some twenty years. Whereas the NPT and CSA in force at the time did not make provision for this, SA adopted a policy of full transparency and issued a standing invitation to the IAEA for inspections "anywhere, any time, any place—within reason." The IAEA inspectors had access to relevant personnel and all sites used for the weapons program, and also witnessed the destruction of the Kalahari test shafts. In September 1993 the IAEA reached the final positive conclusion on the completeness and correctness of the initial declaration with respect to nuclear material inventory and nuclear facilities. Thus, during this period since the accession to the NPT, South Africa has fully cooperated in a transparent manner with the IAEA which has gone beyond the requirements of the NPT and the INFCIRC/153 safeguards agreement.

A newly elected democratic government took over office in April 1994. The entire history up to that date of nuclear development in SA and in particular of the South African Nuclear Energy Corporation (Necsa, initially the Atomic Energy Board (AEB) and subsequently the Atomic Energy Corporation (AEC)) had been shaped by previous governments.

Safeguards Under the Newly Elected Democratic Government

The new government committed itself to a policy of transparency on numerous occasions (e.g., on August 31, 1994, the cabinet decided to implement the policy on the nonproliferation of weapons of mass destruction, Nelson Mandela expressed these views at the OAU head of state summit[2] and at the opening of the forty-ninth session of the UN General Assembly). More recently, in a statement to the 47th General Conference of the IAEA in September 2003, South Africa welcomed the IAEA's effort for increased cooperation with the SSAC. Thus, further development of the South African State System of Accountancy and Control (SSAC) was based on the principles of transparency and good cooperation with the IAEA.

Under the new democratic government the SA safeguards system continued to develop by fully implementing the SSAC, through collaboration on international safeguards activities, promulgation of new legislation and signing of the additional protocol. The commitment of SA to support the international safeguards regime was also demonstrated through serving since 1991 on the IAEA Standing Advisory Group on Safeguards Implementation (SAGSI), obtaining in April 1995 full membership of the Nuclear Suppliers Group (NSG) and in 2004 joining the Member State Support Program (MSSP).

The SA Department of Minerals and Energy (DME) drafted a new Nuclear Energy Act (Act 46 of 1999) that changed the National Authority for implementation of safeguards agreements, from Necsa, a major nuclear facility operator, to the minister of DME. However, the main safeguards activities performed by the SSAC were delegated to Necsa. Within DME a chief director responsible for safeguards handles aspects such as import and export controls and any safeguards agreements with the IAEA or other states.

To strengthen the safeguards system SA was actively involved in the IAEAs 93 + 2 Program in which a trade off between the IAEA verification intensity and the transparency and effectiveness of an SSAC was considered. SA also actively took part in the powerful new safeguards measure of environmental sampling which was tested in field-trails, also in SA.

In September 2002 SA signed the Additional Protocol (AP) and it entered into force immediately. SA was the first African state with significant nuclear activities which had an AP in force. As required of SA the expanded declaration of nuclear materials, facilities and fuel cycle R&D activities was prepared and submitted within the prescribed 180 days. A number of questions and clarifications on the initial declaration were received which were resolved with the IAEA.

State System for Accounting and Control

The South African SSAC was fully established by a small group of personnel in the safeguards function within Necsa. These personnel serving within the Necsa SSAC gained valuable safeguards experience which has been used elsewhere, for example:

- Since 1994 several safeguards personnel have joined the Safeguards Department of the IAEA, and
- A previous manager was appointed to the SA Foreign Affairs Mission in Vienna for dealing with nonproliferation and safeguard matters involving the IAEA, NPT Conference, Nuclear Supplier Group, and Zangger Committee control regimes.

For the IAEA to reach credible conclusions annually on the non-diversion of nuclear material, the SSAC needs to be cooperative and efficient in providing accountancy data, related information, and in enabling the IAEA process of independent verification in a fully transparent manner. The SSAC as operated by Necsa has strived to be transparent and cooperative which has fostered a good working relationship with the IAEA. With regard to the efficiency of the SSAC system:

- The in-house developed software for collecting and checking consistency of nuclear material accountancy data with IAEA reporting requirements has received positive responses from the IAEA. The quality of accountancy data and the timeliness of reports is being modeled as an example of best practice. The experience was shared at an IAEA SSAC workshop, preparation of the IAEA Nuclear Materials Accounting Handbook and presentation at the Seminar for Information Reporting and Processing.[3]
- The use of unattended and remote monitoring was efficiently operated by a Necsa safeguards person, whose input was crucial to the success during the field trials and operation of the present system in SA, and he has subsequently joined the IAEA.

The South African SSAC has established a history of good cooperation with the IAEA as was demonstrated by, for example:

- Voluntary reporting of export of nuclear material and dual use items
- Participation in annual safeguards meetings in Vienna with relevant IAEA safeguards personnel
- Accommodation of special IAEA visits and meetings in South Africa on safeguards matters including the new pebble bed modular reactors (PBMR) facility
- Field trials on environmental sampling and remote monitoring
- Participation in IAEA meetings or in conjunction with the IAEA at international meetings and in African regional seminars and workshops

SA declared its preparedness to strengthen safeguards, in particular for the highly enriched uranium (HEU) material. Thus, since 1996 SA became part of field tests for remote monitoring systems involving several camera systems. During the five years since the start of installation and testing, the SSAC and the IAEA, working together, have succeeded in developing a reliable and robust surveillance system that delivers high-quality visual images directly to the IAEA inspector's desk in Vienna in almost real time.[4] The pioneering work done in SA has identified and solved many technical problems.

To provide added assurance on the various safeguards activities, quality of accountancy data and to foster a culture of implementing best practices and continuous improvement a quality management system (QMS) was implemented for the safeguards system. The South African SSAC obtained ISO 9001 certification in 2003 which was the first or one of the first SSACs, internationally, to have achieved this. The structure of the QMS was presented in a paper[5] at the IAEA Symposium on International Safeguards.

The relatively small SSAC possesses or has access to the following technical capabilities:

- In the past, inspectors were mainly recruited from nuclear facilities within Necsa and have gained experience with the benefit that a diverse range of nuclear facilities exist on a single site at Necsa where the SSAC is also housed.
- Whereas non-destructive analysis (NDA) expertise is available on the Necsa site the SSAC is now embarking on a process to develop it independently in house.
- Independent destructive analysis can be obtained from well-established Necsa analytical laboratories for which some methods are ISO 17025 accredited.

African Region

South Africa is a signatory to the African Nuclear Weapons-Free Zone Treaty (Pelindaba Treaty). This treaty is aimed at "declaring Africa a nuclear weapons free zone" as a vital step in "achieving the ultimate goal of a world entirely free of nuclear weapons" and "strengthening the nonproliferation regime." In order to promote signing of APs in the Africa region a seminar for African states was hosted during June 2002 jointly by the IAEA, UN Center for Peace and Disarmament in Africa, and the Department of Minerals and Energy of SA at which a presentation[6] on the South African SSAC was made. Delegates from some thirty-four African states participated in the seminar.

To train national inspectors of SSACs the IAEA promotes holding of regional training courses. An African regional training course on State System of Accounting for and Control of nuclear material was held in October 2003 in Pretoria. Necsa personnel provided input through presentations of the SA experiences with AP and SSAC, demonstration of the SA remote monitoring system, using SAFARI-1 test reactor as a model facility for the workshop course. This first Africa Regional SSAC course was attended by delegates from ten African States. The value of this workshop makes it certain that future workshops to strengthen African States SSACs would be beneficial.

Further, the IAEA held during March 2004 in Windhoek, Namibia, a workshop on strengthening the safeguards system for states in the Southern Africa region. On invitation SA personnel provided presentations on the SA experience with preparing the state declaration under Additional Protocol and the SSAC system.

A future challenge for SA and the SSAC would be to further strengthen the safeguards system in the Africa region through the Pelindaba Treaty and in particular the Southern African region through closer cooperation and sharing of information on export and import controls, CSA, AP, and SSAC experiences and practices. In this respect the IAEA can play an important role as has been demonstrated through facilitating training courses, workshops and seminars.

Member State Support Program

The objective of the Member State Support Program (MSSP) is to strengthen international safeguards through improvements in the effectiveness and efficiency of safeguards implementation by transferring technology and expertise from member states to the IAEA. South Africa joined the IAEA's Member State Support Program in 2003 and thereby also demonstrates its willingness to contribute to this objective.

The operation of the SA Support Program was delegated to Necsa, who has appointed a chairperson for the SA Support Program Committee, which has members from Department of Minerals and Energy (DME), Eskom (Electrical Utility operating KNPS), Necsa, and PBMR.

Resolution of Anomalies

Since the initial South African declaration it was not possible to quantify and submit for IAEA verification the following:

- Nuclear material hold-up declared as estimates in the initial declaration of nuclear materials. Following on the completion of the decommissioning and decontamination of former nuclear fuel cycle facilities, an IAEA team, together with the SSAC, consolidated the actual recovered nuclear material with the original estimates given during the initial declaration.
- Highly enriched uranium (HEU) and low-enriched uranium (LEU) in the waste storage facility at Necsa. However, in 2001 a non-destructive assay scanner was obtained on loan from the United States. The excellent technical support from the United States and the IAEA as well as financial contribution has now made it possible that all of the HEU waste containing drums have been quantified and has been included in the inventory to the IAEA for verification.[7,9] Currently the scanner is busy with quantifying LEU waste containing drums that are declared on a monthly basis to the IAEA. This long-standing "Problem 1-Prolonged Non-Attainment of Inspection Goal Component" was reported several years in the IAEA Safeguards Implementation Report. Good progress in resolving this difficult measurement problem to quantify the relatively large amount of historical waste has thus been made.

Clandestine Nuclear Network

In October 2003 a foreign shipment of parts of centrifuge enrichment plant to Libya was intercepted. The ensuing investigations involving the IAEA led to the arrest in South Africa of the MD and a director of a local agent and the manufacturer of cascades in South Africa.[8] Court proceedings are expected to resume in July 2007. Some aspects of the court case and indictment are:

- From documents seized it is apparent that from designs, drawings, calculations, and centrifuge test results sourced from an international agent network, a full cascade header assembly for enriching uranium was manufactured by the local manufacturer, who has subsequently turned state witness.
- An attempt to procure Pirani gauges and flow meters from a foreign supplier was unsuccessful due to export control regulations, and the local agent proceeded to manufacture it locally.
- The local agent was asked to supply centrifuges and for this purpose a flow forming machine (dual-use item) was shipped without the necessary authorizations to South Africa and out again.
- The cascade header assembly packed in transport containers would have been shipped as five high-purification water treatment plants.

The alleged misrepresentation, concealment, and violation of South African laws and regulations will be tested in the SA high court. All seized equipment and documents have been placed under IAEA seal and there is close collaboration with IAEA.

South African Border Control

The IAEA has identified certain cross-border activities from South African neighboring countries and made proposals to South Africa to counteract any possible illicit trafficking of possible nuclear material. The South African SSAC was informed about these activities and an investigation was conducted to establish the alleged export activities from neighboring countries to South Africa as well as from South Africa to the international community. Exports such as mineral ores containing uranium and metals (e.g., cobalt and copper) containing high levels of uranium as impurities were investigated. The IAEA sent a security team of experts to evaluate the situation in South Africa and visited all the role players. They proposed the possibility of radiation monitors be installed at borders in South Africa and to train customs personnel on nonproliferation measures.

PBMR Safeguards

A pebble bed modular reactor (PBMR) is being developed in South Africa. The basic reactor and fuel design is regarded as nuclear proliferation resistant, but the high temperature reactor poses unique new safeguards challenges. Based on the process of continuous online refueling of the reactor, the potential for short-time irradiation of target material in the reactor has to be covered by the safeguards approach and safeguards verification methods.

The South African SSAC submitted at an early stage the Design Information Questionnaire to the IAEA for the development of a generic safeguards approach for the PBMR. The envisaged safeguards approach for the PBMR places particular emphasis on process monitoring. The IAEA requested assistance from the MSSP to carry out some necessary studies and for the design and development of safeguards verification methods needed for implementation under traditional safeguards, even though SA is under AP.

Four task proposals were issued by the IAEA to various MSSP members including South Africa and the task results would provide the IAEA with additional information and tools necessary to adequately develop and implement an effective safeguards approach for PBMR facilities.

Transition to Integrated Safeguards

The following are some outstanding issues that need to be resolved before South Africa can move into integrated safeguards:

- The uranium inventory of the state needs to be finalized and this will include the evaluation of the nuclear material inventory of the historical nuclear program in South Africa for all fuel cycle facilities.
- The accuracy of some operator accountancy measurement systems at some nuclear facilities needs to improve.
- The clarification by the SSAC of results of several environmental samples still have to be completed.
- South Africa needs to update its ten-year plan, which will cover all future nuclear projects and R&D activities in South Africa in accordance with Additional Protocol requirements. This is as a result of SA experiencing a nuclear renaissance with the development of its high-temperature reactor, the PBMR, and the suggested need of some ten GW additional installed nuclear capacity by 2020. Additional updated declarations are also required as a result of the rapid and high increase of the uranium price on world markets, which has caused a revival of mining, milling, and extraction of uranium in the state.

Conclusion

After accession to the NPT and the coming into force of the CSA, South Africa has actively cooperated with the IAEA on various safeguards matters. So much so that enhanced cooperation and transparency between the SSAC and the IAEA as demonstrated in the early 1990s has been maintained until the present. The lessons learned from implementation of safeguards in SA and the mutual beneficial cooperation whereby the South African SSAC has provided the IAEA with some experienced inspectors, participated in field trails, collaborated on safeguards projects and matters, and shared information through international, IAEA, and African regional meetings, workshops and seminars has undoubtedly contributed to the improvement of the IAEA safeguards system.

Challenges facing the SSAC are still to address historical nuclear material accountancy issues (although good progress has been made) such as presented by nuclear material in waste and in plant hold up. The clandestine operations, effectiveness of import and export controls and cross-border controls of materials and ores containing uranium are present and future issues facing the SSAC where IAEA expertise and cooperation will be valuable. Transition to integrated safeguards and the SSACs endeavor to become more technically competent in order to perform independent and joint inspections with IAEA will provide further opportunities for strengthening of the safeguards system.

South Africa is embarking on expansion in nuclear energy for which an effective and efficient implementation of the IAEA safeguards system under integrated safeguards for all existing and new nuclear facilities will require additional resources and enhanced cooperation with the IAEA.

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The Evolution of IAEA Safeguards: U.S. Perspectives

Jonathan Sanborn
U.S. Department of State, Washington, D.C. USA

Dunbar Lockwood
U.S. Department of Energy, National Nuclear Security Administration, Washington, D.C. USA

Lisa Hilliard
U.S. Mission to the International Organizations in Vienna,
U.S. Department of Energy, National Nuclear Security Administration, Vienna, Austria

Bruce Moran
U.S. Nuclear Regulatory Commission, Rockville, Maryland USA

Susan Pepper
International Safeguards Project Office, Brookhaven National Laboratory, Upton, New York USA

J. W. Tape
JWT Consulting, Santa Fe, New Mexico USA

Introduction

The first use of the term *safeguards* is often attributed to the Trilateral Declaration issued by United States, the United Kingdom, and Canada on November 15, 1945; in any event the concept and language of safeguards date from the first days of the nuclear era. In January 1946 the very first action of the United Nations General Assembly created a United Nations Atomic Energy Commission "to deal with the problems raised by the discovery of atomic energy and other related matters." The commission was to investigate steps concerning "exchange of information, control to ensure only peaceful use of atomic energy, elimination of atomic weapons and other weapons of mass destruction, and effective safeguards." It was noted that if "the fruits of scientific research should be freely available to all nations," then there needed to be "effective safeguards by way of inspections and other means to protect complying states against the hazards of violations and evasions."[1] Although the initial uses of the word *safeguards* were clearly intended to denote a general concept of *protection*, the specific idea of inspections was already being attached to it, and the word would come to be used consistently in the context of the prevention of misuse of atomic energy.

The evolution of the concept and practice of international safeguards since that time has continued and, for the most part rapidly, with important leaps forward dictated by international events. A seminal accomplishment was the entry into force of the Treaty on the Nonproliferation of Nuclear Weapons (NPT) in 1970. The NPT served to codify International Atomic Energy Agency (IAEA) safeguards in a legally binding treaty and also stimulated further strengthening of the IAEA safeguards system for states that signed comprehensive safeguards agreements with the agency.[2] Legal obligations were assumed by both the state and the agency regarding the application of safeguards to all nuclear materials.

This paper will trace the evolution of IAEA safeguards, from the perspective of the United States, through three broad periods; (1) before the NPT, (2) from the NPT's entry into force in 1970 to the IAEA Board of Governors'(BOG) approval of the model Additional Protocol (AP) in 1997; and (3) roughly the last decade, which has focused on the implementation of the strengthened safeguards system.[3] For each of these periods, we outline changing safeguards concepts and objectives, methods, and technologies, and the U.S. role in their development and evolution. We then attempt to gaze into our crystal ball, and speculate on the future challenges and the further evolution of IAEA safeguards.

Era 1: Pre-NPT

Prior to U.S. President Dwight Eisenhower's Atoms for Peace speech in December 1953, there was no basis for international safeguards—the nuclear technology holders followed policies of secrecy and did not share technology. Following that speech, the U.S. Congress passed the Atomic Energy Act of 1954, which called for an aggressive program of cooperation and aid to countries interested in nuclear energy. One condition was that of verification of peaceful use—in other words, safeguards. At first this involved inspections by U.S. authorities, which were later transferred to the international organization envisioned in Eisenhower's speech, the IAEA.

Safeguards were a fundamental element of the new agency. The Statute Conference determined that the IAEA should "… ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose" (Statute, Article II). The specific inclusion of safeguards in the IAEA statute, and the use of inspections in bilateral agreements for cooperation laid a sound foundation for international safeguards.[4] The statute was thus the first international safeguards document; it established:

- the principle of on-site inspection by a dedicated staff of international professionals,
- examination of facility design, and
- the need for accountability records as a basis for nuclear material verification.

The statute entered into force in 1957. By 1961 the IAEA had issued its first comprehensive technical document clearly describing safeguards, INFCIRC/26.[5] That document answered the question of "what is safeguards" by identifying the following concepts:

- Starting point and scope of safeguards
- Design verification inspections
- Declarations, systems of accounting for materials, and records audit
- Routine and special inspections
- Material unaccounted for
- Confidentiality of information
- An initial notion of "significant quantity"
- Considerations of inspection frequency and inspection effort

INFCIRC/26 addressed only research reactors and power reactors; in fact throughout the 1960s, that is all the IAEA had to inspect. In 1964, for example, the IAEA had safeguards agreements with eleven states covering thirty-six reactors and a safeguards budget of about $0.3 million. Most IAEA safeguards carried out in this era were under arrangements transferred from U.S. bilateral agreements, although there were agency-originated projects as well. To a large extent, the agency's safeguards development work during much of the 1960s focused on systems studies to establish the framework of safeguards for different facility types; this was done in close cooperation with experts from member states. In this context, the IAEA inspected three U.S. research reactors and a power reactor in 1962 "to test its procedures on plants of different design and function."[6]

The United States signed its first safeguards agreement with the IAEA in 1962; this was superseded in 1964 by INFICIRC/57. Among the provisions of INFCIRC/57 was the application of IAEA safeguards to the Yankee Rowe Nuclear Power reactor. This enabled the IAEA to inspect the reactor and verify declarations related to fuel procurement, burnup and disposition. The fuel was discharged from the reactor and transferred to the West Valley Reprocessing Plant where it was eventually processed in 1969 and 1970. This represented the first opportunity for the IAEA to perform inspections related to processing of spent fuel.

The inspections were quite rudimentary by today's standards. The IAEA did not have independent instrumentation and relied on physical verification of operator measurements with operator instruments. Instrumentation was also primitive. Input accountancy volume measurements were based on liquid manometers and plutonium nitrate product measurements were based on weight. Analytical measurements were based on mass spectroscopy. Inspectors were allowed to independently record information from the operator instruments and to witness analytical procedures. The operator material balance summary information was reported to the IAEA through the national system and the IAEA made their verification analysis through comparison to the data recorded on site.[7]

The efforts under this agreement were the first attempts to apply safeguards throughout the full fuel cycle of a reactor core and was the basis for evolving fuel cycle safeguards.

By the end of the decade, INFCIRC/26 had been extended to bulk handling facilities in the form of INFCIRC/66, INFCIRC/66/Rev.1, and INFCIRC/66/Rev.2.

Era 2: NPT to the Additional Protocol

Legal and Political Context

The successful negotiation and initial signing of the NPT in 1968[8] marked a major milestone in the evolution of the nonproliferation regime and international safeguards. With its requirement of placing all nuclear materials in non-nuclear-weapons states (NNWS) under IAEA safeguards, the treaty provided further support and challenges to the still embryonic international safeguards system.[9] As a result of extensive negotiations a new document, INFCIRC/153, became the cornerstone of international safeguards.[10] This document strengthened safeguards in a number of important ways. One is the requirement to place under safeguards *all* nuclear materials in peaceful uses in the state, which would later prove to have significance in determining the agency's authority to search for undeclared nuclear materials and activities. A second is the requirement for states to establish State Systems of Accounting and Control (SSACs) to provide reports to the IAEA. In many countries, these SSACs are also the authority regulating the nuclear activities in the country, including domestic safeguards and security. Finally, the agreement *obligates* the IAEA to apply safeguards; this has implications for IAEA budgets and the funding of safeguards.

U.S. Technical Support to Agency Safeguards

Effective safeguards involve the implementation of technical verification measures, and one of the major U.S. contributions to the IAEA safeguards system has been the provision of a broad range of technical support.

In recognition of the technical nature of safeguards, the

Table 1. Summary of IAEA safeguards implementation at commercial nuclear facility types from 1981-1992. These safeguards activities supported IAEA efforts to demonstrate and refine safeguards approaches for a range of facility types and designs.

Dates	Facility Type	Activities
1981-1983	Research reactor fuel storage pool	Development and testing of safeguards equipment and methods for implementation at research reactors
1981-1988	Power reactors, six total BWRs and PWRs with different design configurations. Each reactor inspected for two years.	Development and testing of safeguards equipment and methods for implementation under different facility-specific conditions at LWRs
1981-1992	LEU fuel fabrication plants, six total Large throughput plants with a variety of designs. Each plant inspected for 2-3 years.	Development of effective and efficient safeguards for fuel fabrication plants with a range of designs, including wet and dry conversion, and producing BWR and PWR pellets and/or fuel assemblies
1983-1985	Large-scale gas centrifuge enrichment plant	Support of Hexapartite Safeguards Project, including development and testing of load-cell based weighing system, cascade header enrichment monitor, gas sampling cart, and neutron flux monitor. Concept developed for mailbox-SNRI approach.

director general (DG) established a Standing Advisory Group on Safeguards Implementation (SAGSI). The DG informed the BOG regarding the appointment of members to SAGSI on May 21, 1975. The United States has actively participated in SAGSI since its beginnings and has supported its work with independent technical studies.

During the 1970s, U.S. laboratories were developing new technologies that could be applied both to domestic and international safeguards problems. The U.S. Program of Technical Assistance to Safeguards (POTAS) was established in 1976 to help transfer these technologies and skills to the IAEA. Activities began in 1977 with the identification of ninety-eight urgent IAEA needs. Initial funding in the amount of $2.6 million from the U.S. Department of State was distributed by the U.S. Department of Energy (DOE) to the International Safeguards Project Office (for program implementation), and to seven DOE national laboratories. Funding was also made available for transfer to the IAEA for procurement of commercially available goods and services.[11]

The technical program was aimed at improving measurement technology, training, systems studies, information processing, surveillance and containment, and support for field operations. Cost-free experts (CFEs) were assigned to work at the IAEA as staff members to help with short-term technical projects A nondestructive assay (NDA) training course for IAEA inspectors also began during the first year of POTAS and emphasized using the same instrument models employed by the IAEA along with representative nuclear materials. The program also made significant contributions to safeguards statistical methodology.

Safeguards Implementation in the United States

To demonstrate that adherence to the NPT does not place other countries at a commercial disadvantage, the United States announced in December 1967 that it would accept IAEA safeguards on its civil nuclear activities, although such safeguards are not required under the NPT for the nuclear weapons states (NWS). The U.S.-IAEA Safeguards Agreement, also known as the Voluntary Offer Agreement (VOA) entered into force in December 1980 and IAEA inspections in the United States began under it in 1981. The IAEA has principally used safeguards inspections in the United States to develop, test, and gain experience with safeguards technologies. Table 1 summarizes IAEA safeguards implementation at commercial facilities under the VOA.

During the period stretching from the 1970s to the early 1990s, IAEA safeguards evolved from a small operation with little technical support to a large, mature enterprise applying sophisticated novel technologies at diverse nuclear facilities around the world. SAGSI and other expert groups, working with the secretariat, helped establish a firm technical framework for safeguards, and the Safeguards Implementation report provided a credible picture of agency activities. Among the developments were technologies for the independent detection and assay of nuclear materials by agency inspectors, containment and surveillance systems, and the development of credible approaches to safeguards at the various new nuclear facility types that were being constructed. Considerable technical and training support from key member states enabled IAEA safeguards inspectors to become experts in their profession. Member state support programs, led by the United States, played key roles in these advances.

Table 2. Summary of USSP activities in support of the IAEA Program 93+2 to investigate methods to increase the effectiveness and improve the efficiency of IAEA safeguards

93+2 Task	USSP Activities	Lessons Learned and Results
Task 2—assessment of potential cost saving measures	Provided CFE for remote monitoring. Supported field trials in Switzerland and Republic of South Africa	Importance of reliable communications technology suitable for the locale Unattended and remote monitoring being implemented in a number of key states
Task 3—environmental monitoring techniques	Participated in field trials of environmental sampling. Provided funding and CFE for construction of the Seibersdorf clean laboratory and associated equipment	Demonstrated feasibility of ES for safeguards applications ES now a central element of safeguards implementation
Task 5—improved analysis of information on states' nuclear activities	Provided CFE to assist in investigating information collection and analysis tools	Information analysis is a central element of the strengthened safeguards system, requiring ongoing development and integration with traditional safeguards tools
Task 6—enhanced safeguards training	Provided environmental sampling training Developed course on enhanced observation skills	ES now a central element of safeguards implementation Inspectors' cultural change to look for indications of undeclared materials and activities

Era 3: Implementing the Strengthened Safeguards System

Legal and Political Context

Following the Gulf War, revelations of Iraq's covert nuclear weapons program and failure to declare significant nuclear activities focused international attention on the limitations of existing safeguards practice, as noted by the IAEA in 2002.[12]

The discoveries in Iraq after the 1991 Gulf War—as well as later revelations involving the Democratic People's Republic of Korea—shattered the assumption that the threats to the nuclear nonproliferation regime lay only outside its ranks.

These events resulted in a major initiative to strengthen the IAEA's ability to detect undeclared nuclear materials and activities known as "Program 93+2." Some identified strengthening measures could be implemented under existing IAEA authorities, such as the early provision of design information and taking of environmental samples at declared facilities. Other measures, such as requiring states to provide additional information on nuclear R&D not involving nuclear materials, and providing broader access to declared sites and other locations, were deemed to require additional legal authority. In 1997, the IAEA Board of Governors approved the Model Additional Protocol,[13] which provides for these additional measures for states that sign and ratify it.

In 2002, the secretariat outlined the basis for the concept of "integrated safeguards" in which the IAEA makes use of the optimum combination of measures available to it under the comprehensive safeguards agreement and the AP. Integrated safeguards is aimed at increasing both the efficiency and effectiveness of safeguards.

U.S. Technical Support for Strengthened Safeguards

The agency's Program 93+2 for investigating methods to increase the effectiveness and improve the efficiency of IAEA safeguards provided new ways for POTAS, or the U.S. Support Program to IAEA Safeguards (USSP), to provide assistance to the IAEA. The USSP contributions to Program 93+2 are summarized in Table 2.

The USSP has continued to contribute to the further evolution of the safeguards system following the completion of Program 93+2. For example, remote monitoring systems were installed in Canada, the Republic of Korea, and several European countries for transmission of data and state-of-health information. Inspectors have commented that having data available from remote monitoring before they leave on inspection is helpful in their inspection planning process. The USSP has also encouraged the increased use of unattended monitoring systems to decrease the need for 24-hour inspector presence at large facilities. Most notably, the implementation of unattended systems at the Rokkasho reprocessing plant is estimated to save at least 900 person days of inspection per year. In some facilities, unattended and remote monitoring techniques are combined for additional savings.

U.S.-supplied cost-free experts have assisted the IAEA in the development of strengthened safeguards in a number of areas including statistical analysis of environmental sampling data, open source information collection and analysis, and establishment of the Satellite Imagery Analysis Laboratory. As new measures were adopted by the IAEA for safeguards implementation and member states began asking for more efficiency with respect to the application of traditional and new measures, the USSP assisted the IAEA with investigations of integrated safeguards techniques.

Activities Under the VOA— Verification of Excess Weapons Materials

Starting in 1994, the United States offered for safeguards—and the IAEA has selected for safeguards inspections—four highly enriched uranium (HEU) and plutonium storage facilities located on DOE reservations formerly involved in the production of nuclear weapons (i.e., Hanford, Rocky Flats, Oak Ridge, and Savannah River). The intent of these activities was to demonstrate that the direct-use nuclear materials removed from the U.S. defense programs were in fact permanently removed from such programs.[14] The cost of safeguards for these activities has been paid for by the United States.

Many of these activities have involved pioneering safeguards techniques. During the IAEA safeguards implementation at the HEU storage vault at Y-12 (near Oak Ridge, Tennessee) the IAEA demonstrated the use of satellite transmission for the monitoring of digital surveillance records and the use of a dial-up interface for the monitoring of digital surveillance, electronic seals, and unattended radiation and weight monitors. A variety of small, low-cost radiation and weight monitors were used on stored items to determine the practicality of such a remote monitoring approach. A plutonium storage facility at the Savannah River Site is now under a remote monitoring safeguards approach in which the IAEA monitors the storage of surplus plutonium by both digital surveillance cameras and radio-frequency seals by secure internet transmission. At other plutonium storage facilities, the plutonium content of containers was verified using authenticated shared-use calorimeters to reduce the need for sampling from the plutonium containers. Change-detection surveillance cameras were introduced to reduce the amount of data that must be stored. Safeguards measures tested in the U.S. vaults have entered routine use in IAEA-safeguarded facilities in other states.

From 1996 through 2000, the IAEA selected the small-scale facility that was down-blending the HEU removed from Kazakhstan in 1994. This facility down-blended an average of slightly more than 100 kg of HEU per year. The IAEA verified the received HEU oxides and uranium oxides on receipt at the facility and applied containment and surveillance to them during storage. Minor isotope analysis of the input and output streams was used to verify that specific materials had been down blended. The down-blending of the HEU was also verified through unattended monitoring of the process operations in the down-blending pencil tanks using measurement of solution volumes, enrichment, and uranium concentrations. The experience gained in this project was used in follow-on larger scale down-blending projects.

The IAEA verified the down-blending of approximately four metric tons of HEU hexafluoride as part of a joint DOE/IAEA verification experiment from 1997 through 1998 at the Portsmouth Site near Piketon, Ohio, USA. The approach used operator declarations to a mailbox, short-notice random inspections, continuous monitoring of feed and withdrawal cylinder weights, continuous monitoring of UF_6 enrichment, and digital camera surveillance of the feed and withdrawal operations. The approach required the IAEA to authenticate the operator's feed and withdrawal load cells; to integrate the cameras with the scale systems to record the attachment and removal of cylinders; and to use motion activated cameras to record activities in the down-blending operations area. The experience gained in this down-blending effort provided experience to the IAEA that has been incorporated into the agency's new model safeguards approach for enrichment plants.

From 1999 through 2006, the IAEA verified the down blending of approximately fifty metric tons of HEU removed from U.S. defense programs. The plant was designed to down blend approximately ten tons HEU per year and to produce approximately 100 tons LEU product as uranyl nitrate crystals. Because of the magnitude of the safeguards effort, the IAEA and the United States developed a new safeguards approach for the down-blending operations to increase efficiency. The safeguards approach relied on continuous, unattended monitoring using on-line and in-line measurement equipment. Continuous measurements of volume, enrichment, and uranium concentration were performed on the process pipes feeding and withdrawing solution from the down-blending tanks. Similar measurements were also performed on the down-blending tanks. The combination of measurements verified the declared flows and verified that the declared quantities of HEU were effectively down blended. The safeguards approach introduced Coriolis flow monitors to the IAEA. These monitors have been subsequently used in a field trial of the IAEA safeguards approach for uranium conversion plants. The safeguards approach also tested use of a more streamlined approach for mailbox declarations that uses a data authentication box that can be attached to an operator's computer. The experience gained by the IAEA in this safeguards approach has provided the IAEA with experience for use in developing safeguards approaches for other high throughput process systems.

The Trilateral Initiative

In 1996 the United States joined with the Russian Federation and the IAEA to explore the technical, legal, and financial issues associated with agency verification of materials removed from defense programs. In what was known as the Trilateral Initiative, the three parties explored and developed technologies for verification of weapons-origin materials with classified properties, developed legal approaches that could be used for negotiating bilateral verification agreements between the IAEA and the two states, and recommended that any verification measures be carried out under reliable and predictable financing mechanisms. Although the verification measures explored by the Trilateral parties were not safeguards *per se,* they drew heavily on safeguards experience. The Trilateral Initiative Joint Working Group concluded its work and reported to the director general, the Minister of Atomic Energy of the Russian Federation, and the U.S. Secretary of Energy in September 2002. As stated in the press release:

The parties concluded that the task entrusted to the Trilateral Initiative Working Group in 1996 has been fulfilled. The work completed has demonstrated practical approaches for IAEA verification of weapon-origin fissile material designated as released from defense programs in classified forms or at certain sensitive facilities. The work included the examination of technical, legal, and financial issues associated with such verification.[15]

Future: Challenges and Further Evolution

The Dynamic Nuclear Environment

Recent history points toward continuing challenges to the safeguards system and the nonproliferation regime generally.

Noncompliance. In December 2002, North Korea expelled IAEA inspectors and disabled IAEA equipment; the IAEA Board of Governors concluded that these actions constituted noncompliance and reported the matter to the UN Security Council. In 2003, IAEA Director General ElBaradei cited multiple *failures* by Iran to meet its safeguards obligations; the Board of Governors adopted a unanimous resolution deploring those failures and breaches, and eventually referred the matter to the Security Council.

The spread of nuclear technology and supply networks. The disclosure in late 2003 of a major clandestine nuclear trade network supplying Libya with nuclear materials, uranium enrichment technology, and nuclear weapon designs provided another wake-up call to the nonproliferation regime and to the international safeguards system. The same network, run by Pakistani nuclear scientist A. Q. Khan, is also suspected of supplying similar technology and information to Iran and North Korea.[16]

The expanding safeguards inspection work load. Renewed worldwide interest in nuclear power, the increasing size and complexity of nuclear facilities, the expanded scope of safeguards responsibilities under the AP, and the possible expansion of safeguards activities into the five NWS and India, all point to continuing conflicts between safeguards needs and available resources.

The international community, including the United States, has responded to these challenges in a number of ways, some still playing out. We outline these below, noting that a detailed treatment is beyond the scope of a paper focused on safeguards:

Increase in the IAEA regular budget. After more than a decade of zero-real-growth budgets the United States took the lead in 2003 in promoting an increase in the IAEA's regular budget, and in particular the safeguards budget. Recently, however, the IAEA has indicated that more funding will be required to address "essential investments."

Fuel cycle initiatives. IAEA Director General Mohamad ElBaradei in October 2003 called for (1) limiting the processing of weapons-usable material in civilian nuclear programs as well as new production by restricting these operations to facilities under multilateral control; (2) deploying nuclear energy systems that avoid the use of materials that may be applied directly to making nuclear weapons; and (3) consideration of multinational approaches to the management and disposal of spent fuel and radioactive waste.[17] Russian President Putin has also raised the idea of an international fuel cycle center, including uranium enrichment, that would be placed under IAEA safeguards, at Angarsk.[18] In May 2006, six countries, including the United States, offered a proposal to the IAEA for establishment of a multi-tiered reliable supply mechanism to provide countries with an assurance of fuel supply without developing uranium enrichment.[19]

U.S. Nonproliferation Initiatives. In a major nonproliferation policy address delivered in February 2004 at the National Defense University, U.S. President George W. Bush, among other things, called for all nations to strengthen domestic laws and international controls that govern proliferation focusing on non-state actors, to expand cooperative threat reduction activities, and to strengthen the Proliferation Security Initiative (PSI). The president also called for the world's leading nuclear exporters and the Nuclear Suppliers Group (NSG) to place restraints on enrichment and reprocessing coupled with nuclear fuel supply assurances, and to make the AP a condition of nuclear supply. Specifically addressing safeguards, Bush proposed the creation of a special committee of the IAEA Board of Governors to focus on safeguards and verification.[20] This committee was established in 2005.[21]

UNSCR 1540. In April 2004 the United Nations Security Council passed Resolution 1540, which includes stipulations that all states shall: (1) refrain from providing any form of support to non-state actors in acquiring or using nuclear, chemical, or biological weapons and their means of delivery; (2) adopt and enforce laws that prohibit any non-state actor from acquiring or using such WMD and means of delivery; and (3) take and enforce effective measures to establish domestic controls to prevent proliferation of WMD, including measures to account for and secure relevant materials, physical protection measures, border controls and law enforcement, and effective export controls.[22]

GNEP. In February 2006, the Bush administration announced the Global Nuclear Energy Partnership (GNEP), which envisions major new nuclear technology developments closely coupled with nonproliferation measures. Prominent among the nonproliferation features are the concept of a small number of fuel supplier states employing advanced technologies to provide assured nuclear fuel cycle services, including fresh fuel supply and spent fuel take back, to a much larger number of fuel user states using a range of tailored reactors to meet their energy demands.[23]

Although some of the nonproliferation and safeguards challenges of this most recent period are new, such as the discovery of an active international black market in sensitive nuclear technologies and the threat of sophisticated international terrorism, many were anticipated in the Acheson-Lilienthal plan sixty years ago. The ElBaradei and Bush proposals to attempt to limit the spread of enrichment and reprocessing are just attempts to address some of the *dangerous* activities described in 1946 within the constraints of today's realities.

Looking Toward the Future of Safeguards

The changing nuclear environment will have a dramatic impact on safeguards implementation. The sections above suggest the likelihood that the IAEA's responsibilities will continue to broaden. Moreover, the ratio of the level of the world's peaceful nuclear activities to the resources available to safeguard them has already forced very significant economies in the way safeguards are carried out, and in both the near-term and long-term this ratio is likely to get larger.

The agency has already begun to respond to these pressures. The IAEA safeguards system in general, and for states under the AP in particular, is evolving to one that looks at the "state as a whole." All information available to the agency about a state is examined and evaluated to reach safeguards conclusions. Safeguards inspectors visiting nuclear facilities, and conducting complementary access visits to additional locations, remain of central importance to the effectiveness of the safeguards system. Observant humans making on-site inspections can provide information not available through other means. However, the role of open source information, including satellite imagery and the Internet, has grown enormously in importance to safeguards. Information acquisition, evaluation, and analysis are a major growth area at the IAEA and can be expected to continue to be of central importance, in particular, for the detection of undeclared materials and activities. Environmental sampling has demonstrated its value in detecting undeclared materials; however, the growing sample analysis load signals the need for careful consideration of the use of this scarce and valuable resource.

Integrated safeguards and the "state-level approach" now allow for much more flexibility and efficiency in the application of safeguards. But while a number of concepts have been identified as important components of a new way to do safeguards (e.g., cooperation and cost sharing with the R/SSAC, randomized inspections, and unattended and remotely monitored—UNARM—instrumentation), more work is needed to articulate a new overall structure for verifying nuclear material.

However, a new verification model may already be taking shape based on these concepts. Versions of the idea are being considered for trials in Japan, and to some extent in Canada. This model can be conceptually as sound as what might be called classical material balance verification, while allowing more flexibility and the possibility of removing some of the resource burden from the IAEA.

In this model, the structure of MBAs and material balance component verification is replaced with a set of verification measurement nodes which connect inventory zones or sectors; these sectors may be large or small or under containment/surveillance or not. The nodes are envisioned as installed UNARM devices measuring 100 percent of the flow of material into and out of the sectors, and are placed so as to be difficult to bypass. The installed instrumentation would be shared (as would the costs) with the state or regional or state systems of accounting and contro.l (R/SSAC). The book inventory in the sectors not under C/S is verified on a random basis. Automation, cost sharing, and randomization all could contribute to a significant reduction in the inspection resources required by the IAEA, without leaving diversion paths unaddressed.

The nodes for a complete fuel cycle might include: the nitrate purification step at a conversion facility; the fuel/waste stations at an enrichment plant, supplemented with other monitoring; the dissolution step at a fabrication plant; the input accountability tank and the output accountability tank in a reprocessing plant; inputs and outputs to powder storage for MOX. Reactors would be safeguarded mostly by C/S.

There are clearly a number of questions that would have to be answered regarding such an approach; for example, in some cases there may be problems sharing installed instrumentation, its maintenance, and the resulting data without compromising effectiveness. One would also have to consider how the randomized inspections impacted detection probabilities. Given a long-term resource squeeze, however, the safeguards community will eventually be faced with difficult choices, and we will need to consider options that maximize efficiency without leaving diversion paths uncovered.

Conclusions

This review indicates how far the legal, technical, and institutional basis for safeguards has evolved in response to the growth and expansion of nuclear energy and technology and the challenges to the nonproliferation regime from a few states.

The development of atomic energy challenged the international community to devise a means of separating its peaceful and military applications. During the twenty-five-year period between the end of World War II and the advent of the NPT, the basic technical concepts and legal underpinnings of safeguards were laid down. This structure required a great deal of work to implement. During the approximately twenty years after the signing of the NPT, the practical means for effectively implementing credible safeguards at a range of nuclear facilities around the world was developed and put in place.

The discovery of a clandestine weapons program in Iraq, as well as the situation in the DPRK, made the nuclear proliferation issue a central focus of the international security dialogue. With this increased emphasis on preventing proliferation came the need to significantly broaden the goals and to enhance the technical capabilities of the international safeguards system. In response, the agency and its member states have been agents for change, modifying and adapting the safeguards system to meet new challenges while maintaining fundamental safeguards principles.

The factors that enabled the international community to address these challenges included an overriding common purpose, a willingness to view the implementation of safeguards from an objective, technical perspective, intensive cooperation among member states and the IAEA, and the ability of technology to overcome verification problems. We are hopeful that these forces will continue to serve us in meeting the challenges ahead. The United States has contributed to the evolution of the IAEA safeguards system over the last fifty years, and we want to continue to do so.

End Notes

1. McKnight, Allan. 1971. *Atomic Scientist: A Study in International Verification* (New York, UNITAR, 1971), p. 4-5.
2. Under Article III.1 of the NPT, each non-nuclear weapons state is obligated to negotiate and conclude a safeguards agreement with the IAEA.
3. This paper will not attempt a comprehensive history of safeguards. Interested readers can refer to the extensive literature on the subject, for example, *The International Atomic Energy Agency and World Nuclear Order,* Lawrence Scheinman, (Washington, DC: Resources for the Future, 1987); papers in *JNMM* Vol. XV, No. 4, July 1987 by S. Eklund ("IAEA Safeguards in Perspective); M. B. Kratzer ("The Origin of International Safeguards"), and W. A. Higinbotham (The Evolution of Safeguards Since Trinity"); and *History of the International Atomic Energy Agency: The First Forty Years,* David Fisher, 1997.
4. Kratzer, Myron. 1987. "The Origin of International Safeguards," *Journal of Nuclear Materials Management* special issue "20 Years of Safeguards at Los Alamos National Laboratory," Volume XV, Number 4, pp. 27-33.
5. The first document specifying the application of IAEA safeguards was INFCIRC/3, April 15, 1959, in connection with supply of natural uranium from Canada to Japan. Procedures were not detailed, and they included inspections for safety as well as non-diversion.
6. David Fisher. 1997. *History of the IAEA: The First Forty Years,* pp. 251-252.
7. Michael H. Ehinger, private communication.
8. The Treaty was opened for signature in 1968 and entered into force in 1970.
9. NPT Article III.1.
10. INFCIRC/153—The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Nonproliferation of Nuclear Weapons.
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Formal Models for NPT Safeguards

Rudolf Avenhaus
Armed Forces University, Munich, Germany

Morton J. Canty
Jülich Research Center, Jülich, Germany

Abstract

A review of the application of decision and game-theoretical models of International Atomic Energy Agency safeguards verification measures as they have developed from the inception of the NPT to the present day is given. Two kinds of formal models are defined: *practical models* for the planning, implementation, and performance evaluation of inspections under INFCIRC/153 and *basic models* for the analysis of integrated safeguards measures under the new protocol. The discussion is illustrated with examples showing the advantages and power of a quantified approach to the solution of safeguards problems.

What is a Formal Model?

This paper is intended to provide a brief overview of the role played by formal models in nuclear safeguards since the inception of the Nuclear Weapons Nonproliferation Treaty (NPT). We will begin with a definition. A formal model, in our sense, will apply established analytical methods (e.g., statistics, quality control, reliability, decision, or game theory) to safeguards activities, and it will do so in such a way as to deliver *quantitative* statements on inspection procedures and their effectiveness. This definition does not exclude heuristic approaches, a well-known example being the "IAEA formula" for deriving inspection sample sizes, see below. But it does mean that we will not discuss the different manifestations of qualitative diversion path analysis, for example the "fuel cycle approach," the many safeguards effectiveness evaluation methodologies proposed over the years, the International Atomic Energy Agency (IAEA) "physical model" and so on, however useful and important these approaches may be.

As ever in the application of methodological tools, one must also clarify for which class of problem they are most applicable. We identify here two different levels of methodology:

- **Practical models** deal with the processing and evaluation of the real inspection data that are needed for the ultimate conclusion drawn by the inspectorate as to the compliance of the state to its commitments under the NPT. Examples are given later in this paper.
- **Basic models** serve to elucidate our understanding of the fundamental nature of a problem. Which parameters characterize a concrete verification task? Are there relationships among these parameters? How can a control system induce legal behavior? Models of this kind are discussed later in this paper.

In the sequel we will trace the evolution of formal safeguards models from the beginnings of the NPT to the present and try to convey their importance and significance to the ongoing verification regime. The references given are merely representative of several hundred published papers, which can be found in the books cited, in specialized journals, and in ESARDA, INMM, and IAEA conference proceedings.

The Negotiation Phase: 1968–1972

At the time that the NPT was set out for signature in 1968, the United States had more than twenty-five years of experience with domestic safeguards and the IAEA had also acquired experience in administering international safeguards in special situations (such as under the Tlatelolco Treaty). Nevertheless it became apparent during the negotiation of the model verification agreement INFCIRC/153[1] that NPT safeguards would pose completely new problems: It was in the interest of the member states to have a system that deterred illegal behavior by "risk of early detection,"[1] but at the same time states in compliance with the NPT had to be protected against false accusations and, in particular, have their compliance officially confirmed. The regime of nuclear safeguards verification procedures was ultimately founded on a compromise, namely the requirement in INFCIRC/153 that material accountancy of *declared nuclear material,* along with containment and surveillance, should play the fundamental role in NPT verification. In a way, this made safeguards synonymous with verifying the conservation of mass under measurement uncertainty: evidently a well-defined and quantifiable task. However, undeclared material and undeclared facilities were not to be the subject of routine verification procedures. To be sure, the instrument of "special inspections" was available that could have been used for this purpose, it was, however, *de facto* never implemented. The INFCIRC/153 system was to be first seriously called into question much later, after events in Iraq and in North Korea.

For the analysis of the control system set out in INFCIRC/153 and for development of the detailed inspection activities associated with it, there existed a considerable base of knowledge which could be made use of. On the one hand, there was a great deal of experience in nuclear technology regarding measurement techniques, establishing material balances and estimating of measurement accuracy.[2,3,4] Stewart[5,6] had already done fundamental statistical work on the material balance problem and proposed the (later very popular) MUF-D statistic to test the non-diversion hypothesis. These approaches were essentially based on the methods of quality control in a non-adversorial environment. On the other hand there were very general game-theoretical models of verification problems,[7,8,9,10] which could be called upon as, in the course of development of error models and statistical sampling theory, it became apparent that game theory, see e.g., see Reference 11, in particular the famous Nash equilibrium solution concept[12] had to be taken into account.

The Implementation Phase: 1972–1993(+2)

Essential to the design and planning of safeguards verification activities for specific nuclear facilities (as set down in the Facility Attachments annexed to each INFCIRC/153-type agreement) was the determination of statistical sampling plans. Procedures for this were laid out in great detail in the IAEA Safeguards Technical Manual.[13] Again, these procedures were oriented toward quality control and their effectiveness in the context of a conflict situation in which deliberate data falsification was—at least theoretically—taking place was not treated explicitly. Two monographs[14,15] addressed material accountancy verification from the game-theoretical point of view and examined the optimality of the essentially heuristic verification procedures practiced by the IAEA.

From the systems analysis point of view, the building blocks of the IAEA's safeguards system were (1) material accountancy, (2) data verification procedures, and (3) a synthesis of the two to come to a final decision regarding legal or illegal behavior. All three aspects required major modelling efforts and we will consider them subsequently in more detail.

Material Accountancy

In April 1977, U.S. President Jimmy Carter, in one of the early acts of his administration, issued a statement on nuclear policy that began with a commitment to defer indefinitely the commercial reprocessing and recycling of plutonium. This emphasized the political sensitivity of commercial reprocessing in non-nuclear weapons states and heralded an intense research effort to improve material accountancy procedures at large bulk handling facilities.

Models of reprocessing plant accountancy are concerned with the processing and evaluation of data in order that material balances for given plants (or parts thereof) over given time periods can be evaluated quantitatively. This may mean the handling of hundreds, if not thousands of data. If one takes into account measurement uncertainties, i.e., if one estimates and propagates measurement variances, then the whole huge machinery of classical statistics is needed. Pioneering work on material accountancy for reprocessing was done at Los Alamos,[17] while accurate accountability tank calibration and especially the concept of "near real time" accounting, i.e., the measurement of intermediate in-process inventories to close the material balance at frequent intervals, received a tremendous amount of attention. [18,19,20,21,22,23,24]

As a first illustration of a formal safeguards model, we shall focus upon a single material balance area and a sequence of inventory periods and pose the question: "Can near-real-time accountancy improve the detection sensitivity of conventional accountancy procedures?," see references 25 and 16.

At the beginning of the first balance period, the amount I0 of material subject to safeguards control is measured in the balance area. Then, during the ith period, *i = 1…n,* some net measured amount Si of material enters the area. At the end of that period the amount of material, now Ii, is again measured. The quantity

$$Z_i = I_{i-1} + S_i - I_i, \quad i = 1\ldots n, \tag{1}$$

is called the *material balance test statistic* for the i-th inventory period. I_t realization in any particular instance is commonly referred to as *material unaccounted for* or MUF. Under the *null hypothesis* that no material was diverted, its expected value is zero because of the law of conservation of matter:

$$E_0(Z_i) = 0, \quad i = 1\ldots n. \tag{2}$$

The *alternative hypothesis* is that material is diverted from the balance area according to some specific pattern. Thus

$$E_1(Z_i) = \mu_i, \quad i = 1\ldots n, \quad \sum_{i=1}^{n} \mu_i = \mu > 0, \tag{3}$$

where the amount μi diverted in the ith period may be positive, negative, or nil, while μ, the total amount of material missing, is hypothesized to be positive.

We now define, for the purpose of determining the best test procedure, a two-person zero-sum game, wherein the set of strategies of the inspector is the set of all possible test procedures $\{\delta_\alpha\}$, i.e., significance thresholds, for fixed false alarm probability α. The set of strategies of the operator is the set of diversion patterns $\mu = (\mu_1 \ldots \mu_n)$, $\mu_i = \mu$. The payoff to the inspector is the probability of detection $1-\beta(\delta_\alpha, \mu)$. The solution of the game is the strategy pair (δ^*_α, μ^*), which must satisfy the *saddle point* conditions (a special case of the Nash conditions)

$$\beta(\delta^*_\alpha, \mu) \le \beta(\delta^*_\alpha, \mu^*) \le \beta(\delta_\alpha, \mu^*) \quad \text{for any } \delta_\alpha, \mu. \tag{4}$$

With the aid of the Lemma of Neyman and Pearson, one of the most fundamental theorems in statistical decision theory, we can derive the following solution for the inspector: His optimal test statistic is

$$\sum_{i=1}^{n} Z_i = I_0 + \sum_{i=1}^{n} S_i - I_n \qquad (5)$$

which is just the overall material balance for the entire time period involved. All of the intermediate inventories I_i , $I = 1\ldots n$ are *ignored.* This gives a very definitive answer to our question whether near-real-time accountancy can improve the sensitivity of a material balancing system. The answer is no.

Satisfying as it may be from a decision theoretical point of view, this result ignores the aspect of detection time. Waiting one year or one complete production campaign before evaluating the overall material balance may be too long to meet timeliness constraints, and therefore test procedures have been discussed that indeed subdivide the year into several inventory periods (at the cost of reduced overall detection sensitivity, as was just explained). To date, it has not been possible to define or to solve satisfactorily a decision theoretical model which takes the critical time aspect into account. By "solve satisfactorily" we mean of course to come up with a best test procedure. Rather, as already mentioned, several heuristic procedures have been lumped together under the label of near-real-time accountancy and their efficiency with respect to various diversion strategies investigated, mostly via Monte Carlo simulation. It has even been proposed to use some of these tests simultaneously. This is a very questionable policy, since the false alarm probability quickly gets out of hand, and it is hardly fair to a legally behaving operator—nor does it contribute to the credibility of a safeguards system—to increase the detection probability simply by increasing the false alarm rate.

Data Verification

To illustrate data verification, we consider first an *attribute sampling* problem where measurement errors do not play a role and where statistical errors arise only due to random sampling. Seal verification on a random basis is a classical safeguards example of such a problem.

For a single class of reported data consisting, let us say, of N similar items, r of which have been falsified where 0rN, we ask how large the inspector's random sample n has to be if at least one of the r falsifications is to be detected with some desired probability 1-β. (Conventionally β is the non-detection probability or *error of the second kind probability* in statistical terminology).

If the number r of falsified items is much smaller than the total number of items N, then 1-β can be approximated from the so-called *hypergeometrical distribution*[16] as

$$1-\beta \approx 1-\left(1-n/N\right)^{r}, \qquad (6)$$

from which the inspector's sample size can be determined.

Now suppose there are K classes of reported data and that an inspectee wishes to falsify his reports by a total amount μ*i.* Let each item of the ith class have magnitude μi. Then the inspectee has to falsify r*i* =μ/μ*i* data of the ith class should he wish to confine his falsification to that single class. If the inspector now determines the class sample sizes ni so as to obtain, for each class, a non-detection probability β under the assumption that the total amount actually is falsified in only one class, then it is easy to show[16] that this non-detection probability is still guaranteed even if the falsification *had actually been distributed in some arbitrary way over the K classes.* This recipe, referred to as the *IAEA formula,* is applied extensively in routine safeguards inspections. The question that a formal model can now answer is: "Is it really an optimal inspection strategy, or could the inspector do even better?" In fact, the use of the IAEA formula to derive sampling plans can be shown to be an equilibrium strategy of an *inspector leadership game,* see e.g., see Reference 16. This demonstrates that the IAEA procedure is indeed optimal under *prior announcement* of the inspection sampling plan.[26]

Next we shall consider *variables sampling,* where statistical measurement errors can no longer be avoided. A decision problem arises since discrepancies between reported and independently verified data can be caused either by measurement errors or by real and intentionally generated differences (data falsification). Stewart[6] was the first to propose the so-called D-statistic for use in safeguards. For one class of data consisting of N items, n of which are verified, the D-statistic is the sum of the differences of reported data X_j and independently measured data Y_j, extrapolated to the whole class population, i.e.,

$$D_1 = \frac{N}{n}\sum_{j=1}^{n}(X_j - Y_j). \qquad (7)$$

For K classes of data (for instance one class for each component of a closed material balance) the D-statistic is given by

$$D_K = \sum_{i=1}^{K}\frac{N_i}{n_i}\sum_{j=1}^{n_i}(X_{ij} - Y_{ij}). \qquad (8)$$

These quantities then form the basis for the test procedure of the inspector, which then goes along similar lines as outlined before: Two hypotheses have to be formulated which permit the determination of significance thresholds for fixed false alarm probabilities and, from them, the associated detection probabilities.

Later on[14,15,16] it was proven, again using the saddle point criterion and the Lemma of Neyman and Pearson, that the use of the D-statistic is optimal for a "reasonable" class of data falsification strategies, and it was shown how the sample sizes can be determined such that they maximize the overall probability of detecting a given total falsification for a total given inspection effort.

Verification of the Material Balance

The basic procedure for IAEA safeguards under NPT agreements is as follows: The facility operator—through his national or multi-national control authority—reports to the agency all data necessary for the establishment of a material balance, the inspector verifies the reported data with the help of independent measurements, and then he establishes the material balance with the operator's data. Literally taken, such a procedure would require two different statistical tests, namely for MUF and for D. It was proposed, originally once again on heuristic grounds and later proven with game-theoretical arguments,[14,15,16] that it is better to use the estimate of material unaccounted for adjusted for the inspector's estimate of the operator's bias D. That is, one should perform a single test based on the statistic

$$MUF - D. \tag{9}$$

This holds for one inventory period. For a sequence of inventory periods it turns out to be optimal to use the statistic

$$\mathrm{var}(MUF)\left(\frac{MUF}{\mathrm{var}(MUF)} - \frac{D}{\mathrm{var}(D)}\right), \tag{10}$$

i.e., a statistic in which the components MUF and D are weighted according to their respective variances. Jaech[27] originally proposed this procedure, again heuristically, and its optimality was later proved rigorously with a game-theoretical model.[15,16]

Undeclared Activities

Following the revelations regarding a clandestine weapons program in Iraq after the Gulf War, and in particular in connection with the 1995 NPT Review Conference, the adequacy of a verification regime based on states' declared nuclear material inventories, as spelled out in INFCIRC/153, was called seriously into question. In the "93+2 Programme" for improving the effectiveness and efficiency of safeguards, the IAEA proposed measures which considerably extended its right to access under the NPT and, furthermore, increased the amount of information made available to it through its member states. This programme culminated in a new NPT safeguards protocol,[31] under which both the obligations of states to provide safeguards-relevant information as well as the scope of inspections have been considerably expanded. As we will see, that a new type of formal model has to be designed in order to evaluate the implications of this program quantitatively.

Integrated Safeguards: 1995–Present

The measures introduced under the new protocol, combined with the "traditional" verification procedures of material accountancy and containment/surveillance, are generally referred to as "integrated safeguards." It is apparent that, if any new verification system is to bring with it an improvement in effectiveness and efficiency, it should not lead to an amplification of the situation in which states with large nuclear fuel cycles and minimal motivation to violate their commitments are most heavily controlled, while other states with obvious motivations are able to deceive the safeguards system successfully. Here, a formal treatment can be of considerable use in analyzing and clarifying a rather complicated and controversial situation. We will illustrate this with two further examples.[28,29] Unlike the preceding *practical models,* these illustrations fall into the category of basic *models* referred to in the introductory section.

Before we go into details, it will be helpful to make some general remarks on the subject of deterrence. The primary objective of any control regime must be to deter the controlled party from illegal behavior. Let us return briefly to a simple attribute sampling problem with one class of items see section 3.2. Suppose that the incentive (perceived gain) of the state for undetected violation is d and the cost of being detected (sanctions) is b. If the detection probability of the inspector's sampling plan is 1-β, then the *expected* gain of the state for behaving illegally is obviously

$$-b \cdot (1-\beta) + d \cdot \beta = -b + (b+d) \cdot \beta. \tag{11}$$

The parameters b and d can be measured relative to the state's gain if it behaved legally, so we can conveniently set that value to be zero. Then the state's decision is simple: it will be deterred from

$$-b + (b+d) \cdot \beta < 0 \quad \text{or when} \quad \beta < \frac{1}{1+d/b}. \tag{12}$$

The agency has hesitated for a long time to consider the explicit use of subjective parameters for the design and planning of its routine inspection measures. Rather it has preferred simply to impose criteria that require necessary non-detection probabilities β, typically $\beta<0.05$. The simple argument above, however, implies that such a requirement is tantamount to saying that d/b > 19: The state's incentive to misbehave is about 20 times larger than its own perception of the consequences of detection! While this might be true for some situations, it is certainly not a reasonable—nor efficient—assumption to make in general.

Before proceeding, let us observe that none of the analyses associated with INFCIRC/153-type verification procedures sketched earlier made use of subjective parameters. They were solely based on the considerations of false alarm and detection probabilities. While this was appropriate to the older safeguards system, and while the deterrence aspect was circumvented in the way just described, the new problems will require an explicit treatment of subjectivity.

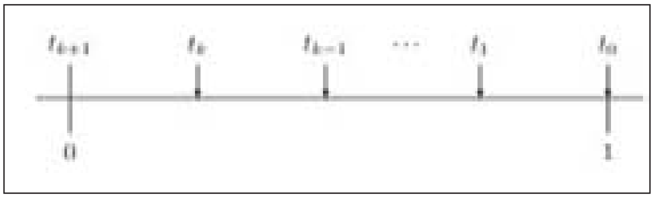
Unannounced Interim Inspections

In the context of integrated safeguards, an often-discussed proposal to reduce routine inspection effort while maintaining the timeliness of an inspection regime is to replace scheduled inspections with a smaller number of randomly chosen, unannounced inspections. The unpredictability aspect of such measures is appealing, as they would seem to place the potential violator in a permanent state of uncertainty and thus serve to deter illegal activity. Sanborn[30] contrasted the intuitive attractiveness of unannounced, random inspections with the substantial practical difficulties of implementing them and with the burden to the inspected party in trying to accommodate them.

To arrive at a formal model which addresses such issues, let us consider a single nuclear facility subject to NPT verification and a reference period of one time unit (e.g., one calendar year). In order to separate the timeliness aspect of routine inspection from the overall goal of detecting illegal activity, we assume that a thorough and unambiguous inspection takes place at the end of the reference period which will detect an illegal activity with certainty if one has occurred. In addition there are a number of less intensive and strategically placed "interim" inspections which are intended to reduce the time to detection below the length of the reference period. An interim inspection will detect a preceding or coincident illegal activity, but with some lower probability $1-\beta<1$. Associated with each interim inspection which is not preceded by an illegal action is a false alarm probability α.

Suppose that there are to be k interim inspections within the reference period. For convenience we label the inspections backwards in time: prior to an inspection at time t_k there are k unused interim inspections available, prior to an inspection at time t_1 there is one interim inspection left and so on. It is also convenient to label the beginning of the reference period t_k+1 and the end t0, so we have $0 = t_{k+1} < t_k <\ldots< t_1 < t_0 = 1$ as depicted in Figure 1.

Figure 1: Sequence of inspections



The utilities of the protagonists (inspector, inspectee) are taken to be as follows:

(0,0) for legal behavior over the reference time, and no false alarm,

($-l$e,$-l$f) for legal behavior, and l false alarms, $l = 1\ldots k$,

($-a\Delta t$, $d\Delta t-b$) for detection of illegal activity after elapsed time $\Delta t \geq 0$,

$$0<e<a, \quad 0<f<b<d. \tag{13}$$

Thus the utilities are normalized to zero for legal behavior without false alarms, and the loss(profit) to the inspector(inspectee) grows proportionally with the time elapsed to detection of an illegal action. A false alarm is resolved unambiguously with time independent costs -e to the inspector and -f to the inspectee, whereupon the inspections continue. The quantity b is the cost to the inspectee of immediate detection. Note that, if b > d, the inspectee will behave legally even if there are no interim inspections at all. Since interim inspections introduce false alarm costs for both parties, there would be no point in performing them. Note also that the preferred outcome from the inspector's point of view is legal behavior: his primary aim is to deter the inspectee from behaving illegally.

We are dealing here with a sequential two-person game with continuous sets of strategies, a complete treatment of which is given in Reference 28. Here we just present the inspector's solution when the payoff parameters are such that the inspectee

$$\frac{b}{d} < A_{k+1} - \frac{f\alpha}{d}(B_{k+1} - k), \tag{14}$$

where A_j and B_j are given by

$$A_j = \frac{1}{1+(j-1)(1-\beta)}, \quad B_j = \frac{j}{2}(1-A_j). \tag{15}$$

In that case an equilibrium strategy for the inspector is given recursively by

$$t^*_j - t^*_{j+1} = (1-\beta)A_{j+1}(1-t^*_{j+1}) - \frac{f\alpha}{d}\Big((1-\beta)B_{j+1}+\beta\Big) \tag{16}$$

for $j = 1\ldots k$ and $t^*_{k+1} = 0$. If, on the other hand,

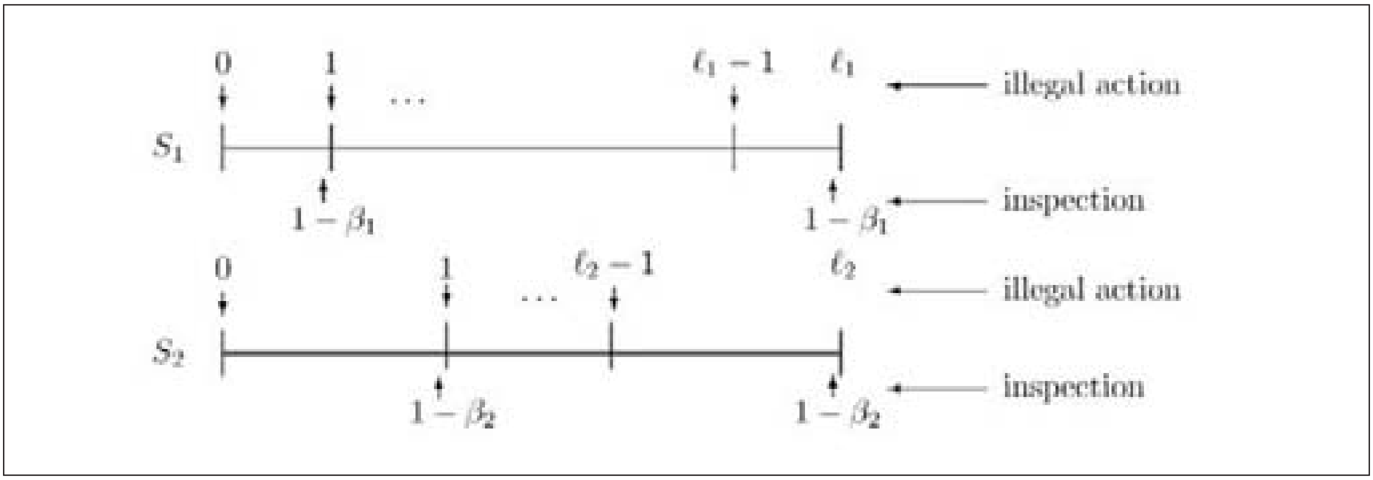
$$\frac{b}{d} \geq A_{k+1} - \frac{f\alpha}{d}(B_{k+1} - k) \tag{17}$$

the inspectee will behave legally, but the above strategy for the inspector is still a Nash equilibrium. This solution looks complicated, and it is. It illustrates that a rigorous, quantitative answer to the question as to how interim inspections should be implemented is by no means trivial. But one aspect can be seen immediately: The inspector's equilibrium strategy is not *mixed*, that is, does not involve any indeterminacy. Thus there is no advantage in randomizing the interim inspections. Since the inspector's strategy is a Nash equilibrium, there is also no advantage whatsoever in not announcing it. The recommended inspection strategy is both deterministic and common knowledge!

The Distribution of Inspection Resources Among States

In order to model the sensitive problem of inspection resource allocation, we consider again a reference time interval, e.g., a calendar year, in which an illegal action, such as a diversion of nuclear material, can occur. Should it occur, the violation will take place within a certain *critical time* during which it may be detected by routine inspection in a timely way, timely in the sense

Figure 2. Two States, each with one facility. The number of critical time periods within the referance interval is l_i, i=1,2. An inspection can occur at the end of any critical time period. An illegal action will occur, if at all, at the beginning of a critical time period



of IAEA safeguards criteria, see, e.g., Reference 32. Let us assume that the agency is dealing with N sovereign states, not cooperating with one another and, for simplicity, that each is in possession of just one declared facility. The facilities have differing numbers of critical times $l_i > 1$, $i = 1 \ldots N$, per reference period. Suppose further that the agency will carry out precisely k inspections within the reference period. If an inspection occurs within the critical time in state i, the inspector will detect the violation with probability 1 β-$_i$. This is illustrated in Figure 2 for two states.

The strategic situation for the protagonists, agency and states, can then be formulated as an N+1–person non-cooperative game with finitely many pure strategies with the agency as "Player" 0 and states as "Players" 1, 2…N. The utilities for the possible outcomes can be expressed as follows (agency, state i):

(0,0) for legal behavior on the part of the state

$(-a_i, -b_i)$ for timely detection of illegal activity

$(-c_i, d_i)$ for no timely detection of illegal activity

where $0 < a_i < c_i$, $0 < b_i$, $0 < d_i$ and $i = 1 \ldots N$. The overall payoff to the Inspectorate is the sum of its utilities in each state, e.g., $-c_1$-c_2 for undetected illegal behavior in states 1 and 2 and legal behavior of the remaining states.

Let us introduce the critical times $\tau_i = 1/l_i$, $i = 1 \ldots N$, which are measured in fractions of the reference period. Then it can be shown[29] that a necessary condition for a Nash equilibrium of the game in which all states choose to behave legally is

$$\sum_{i=1}^{N} \frac{1}{\tau_i} \cdot \frac{1}{1-\beta_i} \cdot \frac{1}{1+b_i/d_i} < k. \qquad (18)$$

This inequality may be understood as a *necessary condition for deterrence of illegal behavior within the entire control regime.* It is expressed in terms of

- the technical capabilities of each state to take fast advantage of undetected illegal behavior, τ_i ,
- the technical effectiveness of the inspections (detection probability), 1 -β_i ,
- the manpower resources available to the inspectorate, k, and
- each state's political incentive to comply with the agreement, b_i/d_i.

We see that, in this condition, all of the parameters are inextricably woven together and, in the rational planning of routine inspections (deciding on required detection probabilities, inspection frequency and detection times), the assessment of states' incentives to illegal behavior and perceptions of the consequences of detection cannot be avoided. Precisely this sort of assessment is implied in the Additional Protocol: states' openness and degree of cooperation in making their activities as transparent as possible should influence the intensity of routine verification effort expended on them.

The Future

The NPT is open-ended: Quantified systems analysis of NPT safeguards will therefore necessarily continue into the future. There are interesting and still unsolved *conventional* problems to be tackled, such as the optimality of sequential material balance testing, the appropriate stratification for variables sampling in the attribute mode, etc. New techniques involving environmental monitoring or satellite remote sensing are posing new questions for quantitative analysis.

Another aspect is the "cross-pollination" with verification systems from other arms control and disarmament treaties. Without doubt the IAEA safeguards system represents the oldest and most clearly specified inspection regime of its kind. It has served as a model, at least in part, for other treaties such as the Chemical Weapons Convention and the Treaty on Conventional Forces in Europe. In the meantime new agreements have been or are being negotiated, and it may be expected that experience with modelling and analysis in different environments, for instance remote monitoring of the Comprehensive Test Ban Treaty, may carry over into NPT verification.

Most important, however, for the further development and healthiness of the NPT safeguards regime will be the recognition on the part of the IAEA that formal, analytical models can help immensely in understanding and clarifying difficult and sometimes contradictory boundary conditions, in giving a clear definition of terms, and in offering a rational basis for measuring and optimizing the much-cited but never defined "efficiency and effectiveness" of integrated safeguards. This will require considerable effort, both on the part of the Inspectorate in showing a willingness to learn and to make use of the powerful methods of systems analysis, as well as by the analyst in making his or her often non-trivial explanations understandable and plausible to the practitioner. We trust that our review of formal models for NPT safeguards has contributed to this effort.

Rudolf Avenhaus is professor of statistics and operations research at the German Armed Forces University Munich. Prior to his academic appointment in 1980, he studied physics and and mathematics at the University of Munich and received his diploma in 1964. Thereafter he was research assistant at the Universities of Karlsruhe and Geneva and received his doctorate in 1967. From 1968 to 1980 he was research scholar at the Nuclear Research Center Karlruhe. In between, from 1973 to 1975 and again in 1980 he worked at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg near Vienna. In 1974 he obtained his venia legendi *in statistics at the University of Mannheim. He is author of numerous scientific papers in physics, statistics and game theory, in particular with applications to inspection problems. He is author of the books* Material Accountability *(Wiley 1977), for which he received the Oce-van-der-Grinten Award,* safeguards Systems Analysis *(Plenum 1986) and* Compliance Quantified *(with M. Canty, Cambridge University Press 1996) and is co-editor of eight additional books. In 1989 and 1990 he was dean of his faculty, in 1993 and 1994 vice president and during that time for one year acting president of his university. Since 1996 he is Steering Committee member of the Processes of International Negotiations (PIN) Program at IIASA.*

Morton J. Canty is a senior research scientist at the Jülich Research Center in Germany. He received his Ph.D. in nuclear physics in 1969 at the University of Manitoba, Canada. He visited the University of Bonn for three years on a National Research Council of Canada and Rutherford Postdoctoral Fellowship, did research at the University of Groningen as a guest scientist and worked for two years at the University of Marburg and the Heavy Ion Accelerator Laboratory (GSI) in Darmstadt. He began his present position in Jülich in 1979, where his principal interests have been the development of statistical and game-theoretical models for the verification of international treaties and the use of remote sensing data for monitoring global treaty compliance. He has served on several advisory bodies to the German federal government and to the International Atomic Energy Agency in Vienna. He has published numerous scientific papers on the subjects of low-energy nuclear physics, nuclear safeguards, applied game theory and remote sensing. He is the author of the books Compliance Quantified *(with R. Avenhaus, Cambridge University Press 1996),* Resolving Conflicts with Mathematica *(Academic Press 2003) and* Image Analysis, Classification and Change Detection in Remote Sensing *(Taylor and Francis 2007). His homepage can be found at http://www.fz-juelich.de/ste/remote_sensing.*

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The Development and Implementation of NDA Equipment at the IAEA

H. O. Menlove and T. D. Reilly
Los Alamos National Laboratory, Los Alamos, New Mexico, USA

Abstract

With the implementation of the Nonproliferation Treaty (NPT) in the 1960s, the International Atomic Energy Agency (IAEA) needed the technical capability to independently verify the declared inventories of nuclear materials in the signatory countries. This requirement led to the development of technology that included an array of nondestructive assay (NDA) instrumentation that has continued to progress to the present day. During the forty years of development, NDA has evolved to keep pace with the improvements in sensors and electronics as well as the changing requirement of the nuclear materials and facilities. The initial NDA effort focused on portable equipment that could be transported from Vienna to sites around the world for inspectors to use in the field. Key requirements for the equipment were simplicity and robustness to accommodate the training, transport, and use. Inspectors were expected to be qualified for field use of the large array of NDA equipment that included gamma-ray, neutron, and optical systems. This requirement necessitated the development of a substantial training effort in Vienna and in the Member State Support Programs (MSSP). There has been a continuing need for the training programs because of the turnover of the inspector staff and the changes in the technical requirements and equipment.

Introduction

This paper is a technical review looking back and forward in the area of non-destructive assay (NDA). In the beginning, 1957, safeguards was a relatively minor concern of the International Atomic Energy Agency (IAEA). The first safeguards inspection only occurred in Sweden in 1962. The entry-into-effect of the Treaty on the Nonproliferation of Nuclear Weapons (NPT) in 1970 altered this situation and now the Safeguards Department is the agency's largest.

NDA equipment has focused on gamma ray and neutron sensors because of their ability to identify and quantify most forms of nuclear materials. Many of the techniques for measuring nuclear materials were developed for domestic programs in member states during the two decades prior to the NPT. In general, this equipment was modified and improved to meet IAEA requirements. The IAEA instituted a system to standardize equipment types to simplify maintenance and training requirements.

In the mid-1980s, a new paradigm was introduced in that portable NDA equipment was no longer adequate to verify the nuclear materials in large-scale automated plants. Throughputs were too high and nuclear materials could not be removed from the process lines to be measured in portable equipment. This led to the development of installed NDA equipment that operated continuously. The continuous data collection and analysis required the development of extensive software and electronics. Data transmission and authentication issues became very important to the IAEA. The explosion of data and information presents a real challenge to the IAEA, but, on the positive side, the effectiveness of the safeguards system has been significantly improved by installed equipment operating continuously in the absence of inspectors.

This paper presents the development and implementation NDA equipment at the IAEA over the forty-year period from 1967 to 2007.

NDA Background from Member States

From the start of the use of nuclear materials in member states in the 1950s, it was necessary to measure nuclear materials for accountability, criticality control, safety, and health physics—safeguards came along later. These requirements led to the development of instrumentation to measure radiation from nuclear materials and were the starting point for NDA development. However, much of this equipment was large and complex and required a trained physicist to operate. In general, the instruments used for health physics could not be used for quantitative mass measurements.

The Los Alamos National Laboratory (LANL) safeguards program was initiated in 1966 and the array of NDA equipment included laboratory-type measurement equipment inherited from prior domestic programs. The focus of the original effort was to develop NDA technology and equipment for measuring nuclear materials with a focus on domestic nuclear sites. The neutron generators that were available at LANL at the time included the Cockcroft Walton accelerator and a new Van de Graaff accelerator. These two neutron generators and the fast-critical-assembly equipment naturally led to a focus on neutron-based NDA technology development. However, because the complementary nature of neutron and gamma-ray measurements was recognized from the outset, both approaches were actively pursued.

In 1970, LANL organized a nuclear safeguards exhibit area at the Atoms for Peace Conference in Geneva, Switzerland. This activity helped trigger the Los Alamos technical support effort to the IAEA, and for the past thirty years, Los Alamos has been a leading supplier of technical support to the agency. LANL has hosted IAEA training courses each year for the past three decades, and nearly all of the past and present IAEA inspectors have received training at Los Alamos.

Figure 1 shows the Stabilized Assay Meter (SAM-2) being used in a 1969 domestic program to measure the enrichment of UF_6 cylinders at the Uranium Enrichment Plant (K-25) in Oak Ridge, Tennessee, USA. The SAM-2 electronics could be used for both totals neutron and gamma-ray counting. The SAM was designed and built by the Eberline Corporation originally with one single-channel analyzer (SCA) and scaler-timer. After consultations with Los Alamos, they added a second SCA so that the unit could be more easily used for ^{235}U enrichment measurements based on the 185.7-keV gamma ray. Then renamed the SAM-2, it was sold to the IAEA and became the first widely used NDA instrument at the agency. Later, at agency request, LANL added a digital rate multiplier (DRM) so the unit could read directly in percent ^{235}U (Figure 2). At one time, the IAEA had nearly 300 SAM-2s.

Figure 1. The application of the SAM and NaI detector for UF_6 enrichment in 1969 by Roddy Walton at the K-25 plant at Oak Ridge

Figure 2. The Eberline SAM-2 electronics module with digital rate multiplier used for low resolution gamma-ray measurements and neutron totals counting

NDA Development for the IAEA

Gamma-Ray Based NDA Systems

As the focus of NDA development shifted to the needs of the IAEA, it became clear that portability and simplicity were essential. A variety of commercial instrumentation was evaluated and adapted for IAEA use. Several different types of gamma-ray-based detectors were available, some from commercial sources, including:

- Low resolution gamma-ray spectroscopy, NaI detector
- Nokia MCA
- SAM-2, Eberline Corporation
- BSAM, Brookhaven National Laboratory
- HM-4, Brookhaven National Laboratory
- HM-5, Target Company

High Resolution Gamma-Ray Spectroscopy HRGS, HPGe detector

- Silena B27, Silena Company, Italy
- Silena Cicero
    - Blue Box, Livermore National Laboratory, Pu isotopic analysis
    - Microprocessor installed in Cicero, Pu isotopic analysis
- Silena Cato
- Davidson PMCA, LANL, used with NaI and HPGe
- ORTEC SX-90 with PC running MGA for Pu isotopic analysis
- Rosendorf Institute MMCA, used with NaI and HPGe
- Canberra InSpector 2000, IMCA, with PC running MGA/U for Pu and U isotopic analysis

Gamma-ray spectroscopy is used by the IAEA almost exclusively to determine the isotopic composition of uranium and plutonium materials. At first, NaI was the only detector available to the agency and uranium enrichment measurements with the SAM-2 were the principal NDA measurements made by inspectors. The successors to the SAM-2 were the BSAM and the Handheld Monitor, HM-4, designed by Marty Zucker at Brookhaven National Laboratory. The HM-4 became the most popular instrument with inspectors because it was light and very easy to use for gross defects (Method H) measurements and the determination of the active length of fuel assemblies. It contained a small NaI crystal with stabilization and counting electronics similar to the SAM-2.

Twenty-five years later the German Support Program developed a replacement for the HM-4, called the FieldSPEC or HM-

Figure 3. The handheld monitor HM-5 used for safeguards (method H and active fuel length) and illicit trafficking measurements

5 (Figure 3). This still uses a NaI detector; CdZnTe is also available, but has a better stabilization technique and includes software for nuclide identification and many other measurement and analysis procedures. This instrument was developed for safeguards and illicit trafficking applications.

The gamma-ray spectrum of plutonium is too complex to analyze with NaI. The initial germanium detectors were lithium-drifted and required constant cooling with liquid nitrogen. This requirement made them unusable for inspectors. By the mid to late 1970s, germanium crystals could be grown sufficiently pure so that the lithium process was not required and the resulting detectors only needed liquid nitrogen during use. This allowed easy transport, storage, and shipping and the IAEA began to study their application, especially for determining plutonium isotopic composition. The first multichannel analyzer (MCA) at IAEA headquarters was manufactured by Nokia, the same Finnish company that dominates the modern cell phone market. The first MCA used routinely by inspectors was the Silena B27 manufactured in Italy. This was used with NaI and HPGe detectors for U and Pu measurements. The plutonium measurements were gross-defect tests that only verified that the spectrum was indeed that of Pu. A simple program in an HP-97 calculator was tested to verify isotopic composition.

In the early 1980s, a truly portable MCA was designed by Jim Halbig and programmed by Shirley Klosterbuer at LANL (Figure 4). The IAEA code for this instrument was PMCA and it became their workhorse for gamma-ray measurements for the next twenty years. The PMCA operated with NaI and HPGe and had special software for uranium enrichment measurements with either detector. Toward the end of its lifetime, the PMCA was used with MGA running in a laptop computer to analyze Pu isotopic composition, but by then newer, smaller, and faster MCAs were available commercially.

The first truly usable isotopic composition measurement was provided by Lawrence Livermore National Laboratory in a separate microprocessor, "Blue Box," that took spectral data from a Silena Cicero MCA for analysis using an early version of Ray Gunnink's Multi-Group Analysis (MGA) program (Figure 5). The slow computing speed of the time meant that the analysis of a single Pu spectrum could take as long as fifteen minutes.

Figure 4. The Davidson Portable Multichannel Analyzer (PMCA) with a HPGe detector. The PMCA was the IAEA gamma-ray workhorse for twenty years.

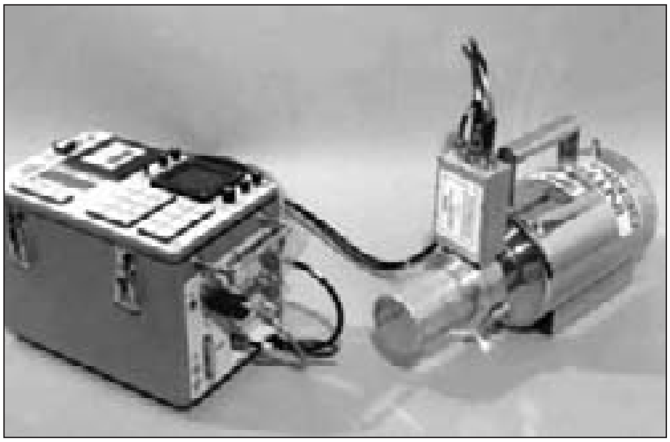


Figure 5. Silena Cicero MCA with LLNL's "Blue Box" plutonium isotopic analyzer. This was the first true Pu isotopic analysis system used by the IAEA.

The next step was to build a faster microprocessor into the Cicero; this instrument was used for several years to verify isotopic composition. As the speed of portable (laptop) computers increased in leaps and bounds, it became possible to run MGA in a laptop and download spectral data from an MCA. A system was developed by the Silena Company that used an ORTEC SX-90 spectrum analyzer (computer controlled, blind MCA). By now, analysis speed was no longer an issue. The operator interface written by Silena was extremely easy to use and very reliable. As computers, detectors, and electronics advanced, LLNL improved the MGA code to handle MOX spectra, obtain more accurate results, and determine uranium isotopic composition using a modified program, MGAU.

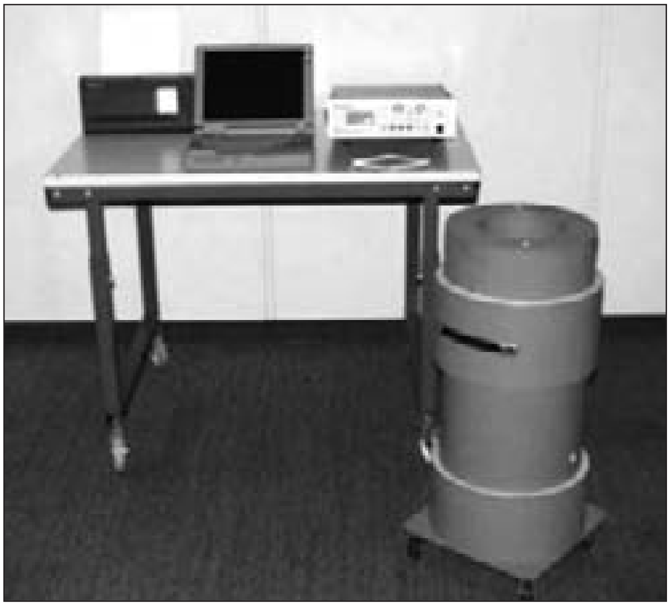
Figure 6a. InSpector-2000(IMCA) and Mini-Multichannel Analyzer (MMCA) are now the preferred gamma-ray instruments at the IAEA.

Figure 6b. InSpector-2000(IMCA) and Mini-Multichannel Analyzer (MMCA) are now the preferred gamma-ray instruments at the IAEA.

By the late 1990s, the SX-90 and the Davidson PMCA became unavailable as did replacement parts. The German Support Program developed a very small portable MCA at the Rosendorf Institute in Dresden. The Mini-Multichannel Analyzer (MMCA) was more powerful than either of the older MCAs and could perform all of the gamma-ray spectroscopic measurements needed by inspectors. Most of the measurements could be performed using a very portable Palmtop computer from Hewlett Packard (Figure 6a). At about the same time, the United States Support Program offered a number of commercially available MCAs, Canberra Instruments' InSpector 2000 (Figure 6b), to the IAEA. The agency code for these instruments is IMCA, and it can perform all of the functions of the MMCA. Canberra wrote a special program, also called IMCA, to facilitate inspector operation of the IMCA.

At present the IAEA has a large number of NaI, CdZnTe, and HPGe detectors that are used with the MMCA and IMCA for uranium and plutonium measurements. When used with HPGe detectors, either MCA can analyze U, Pu, and MOX isotopic composition using MGA and MGAU.

Figure 7. The HLNC-II and JSR-12 electronics used in portable applications by the IAEA for verification of bulk plutonium and MOX samples



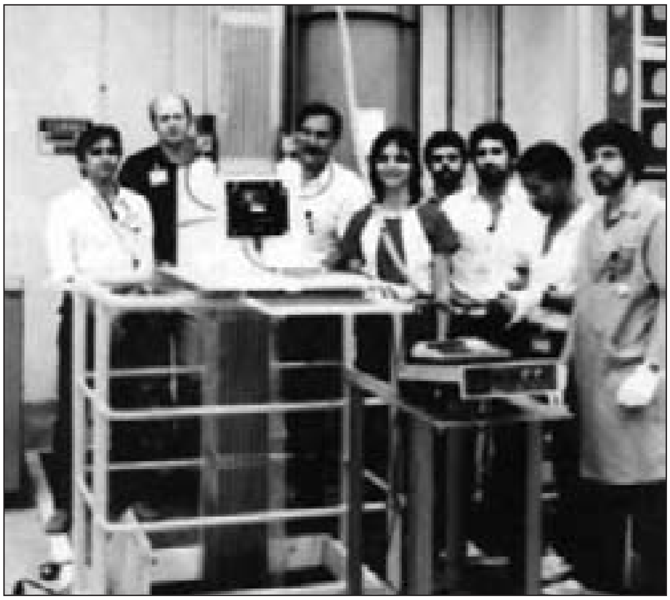
Neutron-Based NDA Systems

A basic distinction in neutron systems is whether the detector measures total neutrons (singles), coincidence neutrons (doubles), or multiplicity neutrons (triples). The efficiency must increase for each of the steps. The early IAEA equipment measured only singles and had low efficiency and simple electronics. These instruments were used to locate nuclear material and to measure enriched UF_6 and plutonium.

- **SNAP and SAM electronics**—The shielded neutron assay probe (SNAP) was used for directional totals neutron measurements where back shielding from room neutrons was needed. It contained only two short^3 He detector tubes, had low efficiency, and was used for totals neutron counting. An important application was the measurement of the UF_6 mass in storage cylinders. The SAM-2 could be used for both gamma enrichment measurements and passive neutron counting. The Stabilized Assay Meter (SAM-2) was used to provide power to the detectors and collect the data for both neutron and gamma probes.
- **HLNC and HLNC-II**—The High Level Neutron Coincidence Counter (HLNC)[1] was developed to provide a quantitative measurement of Pu mass in bulk samples. The HLNC system was used to measure time correlated (coincidence) neutrons from the $^{240}Pu_{eff}$ in an eighteen ^3He tube hexagonal well detector. After several years of field use, the IAEA and LANL developed an upgraded system, the

Figure 8. The AWCC with the MTR fuel element insert and JSR-12 electronics used for the verification of ^{235}U in bulk samples and MTR fuel assemblies

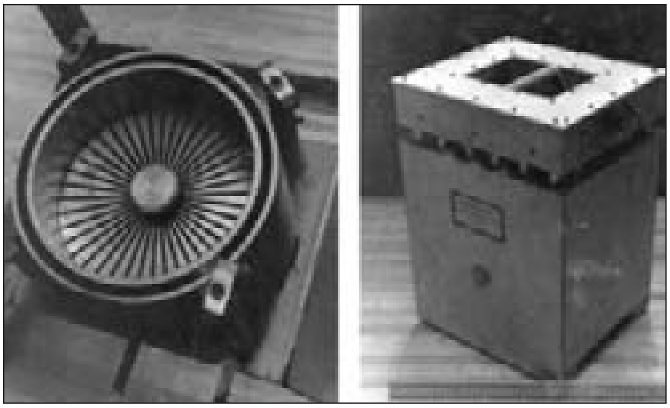
Figure 9. The UNCL used for the verification of PWR fuel assemblies at Resende, Brazil, in 1980



HLNC-II shown in Figure 7. This system contained eighteen ^{3}He tubes and six internal amplifiers (AMPTEX A111) that provided a much faster counting capability (up to 1.5 MHz). It was the first IAEA system that could measure Pu samples from less than 1g up to ~ 7kg of high burnup Pu. What made the high performance possible were the 17.8 percent efficiency and the parallel development of the shift register (SR) digital electronics. This system can measure $^{240}Pu_{eff}$ to an accuracy of 1 percent to 3 percent for PuO_2 and MOX product material. Added capability was needed for impure scrap and recycled Pu. A commercial vendor (JOMAR/Canberra) was established for this system, and it became the first member of the neutron detector family where dozens of identical detectors have almost identical calibration constants.

- **Active Well Coincidence Counter (AWCC)**—^{235}U presents a problem for passive neutron measurements because the spontaneous fission rate of the uranium is too low for practical measurements. A portable active neutron assay system was needed for the ^{235}U mass measurements. This need led to the development of the AWCC[2] that made use of a pair of AmLi neutron sources to interrogate the bulk uranium samples. Figure 8 shows the AWCC that has one AmLi source in the bottom end-plug and a second source in the lid. The body of the AWCC contains forty-two ^{3}He tubes in two rings that surround the sample cavity. The AmLi neutrons are produced randomly from α,n reactions; whereas, the induced fission reactions emit more than one neutron in coincidence, so the coincidence counting separates the ^{235}U fissions from the much more numerous interrogation neutrons. The AWCC measure 1-50g samples in the thermal-neutron mode and 50-5000g samples in the fast-neutron mode (with the Cd liner). The accuracy is typically 2 percent to 4 percent, but can be improved to <1 percent for cases where the calibration samples are similar to the unknowns. The AWCC is produced commercially (Canberra) and has been in use for more than twenty-five years. It has been a key IAEA tool for verification of ^{235}U in the conversion of HEU weapons material to peaceful purposes.
- **Neutron Collar (UNCL and UNCL-II)**—The UNCL[3] operates with the same basic technique as the AWCC, but the sample has changed from a can to a four-meter-long fuel assembly. A single AmLi neutron source is used to interrogate the ^{235}U in the fuel assemblies, and coincidence neutron counting is used to determine the ^{235}U mass per unit length. The original UNCL contained eighteen ^{3}He tubes and provided an accuracy of 2 percent to 4 percent in a 15-minute measurement. The UNCL is in use at LWR fabrication plants worldwide. Figure 9 shows the UNCL in use in Brazil.
- **Passive Neutron Collar (PNCC)**—The neutron collar was adapted to verify the Pu content in fresh LWR fuel containing MOX. For the PNCC[4], the AmLi source was replaced by a fourth detector bank to provide a passive neutron coincidence count of the fuel assemblies. The active length of the assembly was verified using a gamma detector such as the HM-5.
- **Inventory Sample Verification System (INVS)**—In 1981, the IAEA introduced the INVS[5] for the verification of small samples that were used to verify bulk materials in process areas. This system was normally used underneath a glove-box so that the samples could be measured through a pipe extending below the box. In some cases, there was an associated HRGS system to verify Pu isotopic ratios.

Figure 10. The Pu coupon bird cage and the custom-designed detector (BCNC) to fit inside the criticality safety storage container at the Fast Critical Assembly in Japan



- **Passive Neutron Scrap Multiplicity Counter (PSMC)**—The need to verify impure plutonium and scrap led to the development of the neutron multiplicity counters. The first IAEA application of multiplicity counting was with the PSMC[6] at a MOX fabrication plant in Japan. Multiplicity counters require high efficiency to provide good statistical precision for the triples neutron rate. Multiplicity counting gives good accuracy for the Pu mass in impure samples. The PSMC contains eighty bes providing an efficiency of 55 percent, counting times of 15-30 minutes, and accuracies of 1 percent to 3 percent for the $^{240}Pu_{eff}$.
- **Epithermal Neutron Multiplicity Counter (ENMC)**—The ENMC[7] was developed for the measurement of impure plutonium and MOX samples that have high alpha values. It can also be used for small samples and to create secondary standards from production materials. The parameters that determine the performance of neutron multiplicity detectors include efficiency, die-away time, count-rate capabilities, stability, and resistance to gamma-ray interference. For the ENMC, the efficiency is 64 percent, the die-away time is 19.1 µs, the maximum counting rate is ~2.0 MHz, the stability is 0.02 percent, and gamma-ray resistance is ~1 R/h for the sample on contact. The most important parameter for multiplicity counting is the efficiency because the triples rate varies with the efficiency cubed.

The above equipment is applicable to a large variety of plutonium and uranium samples. They were developed in cooperation with the IAEA, and the design was transferred to commercial vendors. This family of detectors made it possible to calibrate one unit with standards and apply the same calibration to all members of the *family*. It also greatly simplified maintenance, spare parts documentation, and training.

Figure 11. The "neutron tree" illustrates the relationship of portable neutron NDA systems and their applications by the IAEA as of 1986. The installed equipment listed in Table 2 came into use after that time.

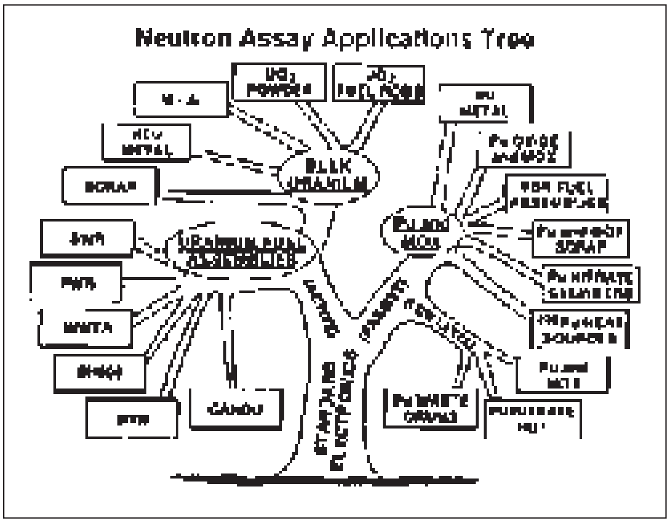


Table 1. Custom geometry NDA systems for special use by the IAEA

Acronym	Reference Item	Purpose
UFBR	Universal Fast Breeder Reactor assemblies	Verification of Pu in FBR fuel assemblies
PLBC	Plutonium Nitrate Bottle Counter	Verification of Pu nitrate in bottles
DRNC	FCA Coupon Verification in drawers	Verification of Pu metal coupons
CNCC	Channel Neutron Coincidence Counter	Verification of Pu components
BCNC	FCA Coupon Bird Cage Counter	Verification of Pu coupons in storage cans
UWCC	Underwater Coincidence Counter	Verification of fresh MOX fuel assemblies
CALR	Calorimeter evaluation unit	Measurement of heat from small samples

In addition to the above-mentioned detector families, the neutron coincidence method was applied to many measurement applications where a custom designed detector head was required; some of these are listed in Table 1. Figure 10 shows the bird cage neutron counter (BCNC) that is used by the IAEA to verify the Fast Critical Assembly (FCA) fuel plutonium coupons that are stored in canisters inside criticality safety cages. The custom counter was designed to drop inside the cage for the portable measurement.

The family of neutron NDA systems that have similar physics principles and can operate with the shift-register (SR)[8] are illustrated in Figure 11. The IAEA applications are for plutonium in the passive neutron coincidence mode as well as for HEU and fuel assemblies in the active neutron interrogation mode. Almost all of the neutron NDA systems can operate with a single

Table 2. Installed NDA systems in use by the IAEA

Acronym	Reference Item	Purpose
PCAS	Plutonium Canister Assay System (4 systems)	Verification of 100% of MOX canisters
MAGB	Material Accountancy Glove Box system (4)	Verification of MOX in process
A-MAGB	MAGB plus HRGS through glove box (2)	Neutron Coincidence and Pu isotopic ratios
FPAS	Fuel Pin Assay System	MOX pin tray verification
FAAS	Fuel Assembly Assay System	Complete MOX FBR assembly verification
GBAS	Glove Box Assay System (4)	NDA for Up holdup in glove boxes
SBAS	Super Glove Box Assay System (4)	Advanced holdup measurement system
WDAS	Waste Drum Assay System plus HRGS (5)	Measure Pu mass in waste drums
WCAS	Waste Crate Assay System (3)	Measure Pu mass in waste crates
HMMS	Hulls Measurement and Monitor System	Uses Cm/Pu ratio to measure Pu in hulls
VWCC	Vitrified Waste Coincidence Counter	Measures Pu in vitrified waste canisters
iPCAS	Improved PCAS plus HRGS	Verification of MOX cans at bias-defect
TCVS	Temporary Canister Verification System	Verification of in-process glove boxes
PIMS	Pu Inventory Measurement System	Measures the Pu in the process glove boxes
RHMS	Rokkasho Hulls Measurement System	Verification of hulls using Cm/Pu ratio
VCAS	Vitrified Canister Assay System	Measures Pu in canister using Cm/Pu ratio
HKED	Hybrid K-Edge Densitometer	Measures the U and Pu in reprocessing samples
FRSC	Fuel Rod Scanner Counter	Verification of LEU fuel rods (operator systems)

electronic module called a Shift-Register that is illustrated as the trunk of the tree.

The SR electronics has developed over a thirty-year period as illustrated in Figure 12. Each of the changes introduced faster circuitry and auxiliary features such as inputs for multiple scalers and internal data storage and buffering. The initial SR modules were limited to counting rates under 50KHz, but with the advance of digital electronics and computer speeds, the current units such as the JOMAR/Canberra JSR-12 can operate for rates up to 2MHz, and faster modules are under development.

A key activity for the implementation of the many types of neutron coincidence systems was the development IAEA Neutron Coincidence Counting (INCC) software by M. Krick and W. Harker. This software is used to set detector parameters, collect data, make dead-time and background corrections, calculate statistical errors, perform data quality tests, convert counts to grams plutonium, and to calibrate the systems. All of the NDA systems covered in this paper can make use of the INCC software, and it has greatly simplified the IAEA training and field applications.

The most recent shift register in use by the IAEA is the Advanced Multiplicity Shift Register (AMSR)[9] that has the added feature of sorting the full multiplicity distribution of the neutron pulse stream. The subsequent INCC software can determine the singles, doubles, and triples from the fission events. The three measured parameters make it possible to accurately measure Pu containing impurities and scrap materials.

Installed NDA Systems

There was an important shift in the NDA used by the IAEA that started in 1986 with its application as installed, unattended systems with continuous data collection. These systems were installed in automated MOX plants such as the Plutonium Fuels Production Facility (PFPF) in Japan and introduced significant development in authentication techniques and data collection software. Table 2 lists some of the installed systems that are in current use by the IAEA.[10] The first eleven systems in Table 2 are installed at PFPF and the Tokai Reprocessing Plant (TRP) and have been in continuous use for the past twenty years. The next five systems were recently installed at the Rokkasho Reprocessing Plant (RRP) and are in the process of calibration and software testing.

The most important safeguards measurement points are the input and output of a nuclear facility. For a fabrication facility, the output product can not be sampled for destruction analysis (DA) without destroying the product and NDA techniques are required. Figure 13 shows the PCAS at the PFPF where the installed system is the key measurement point for the MOX input, and Figure 14 shows the FAAS for the fuel assemblies at the output. The neutron

Figure 12. The illustration shows the evolution of the shift register (SR) electronics for IAEA neutron detector support over a thirty-year period. All IAEA coincidence and multiplicity detectors could operate with the then current versions of the packages.

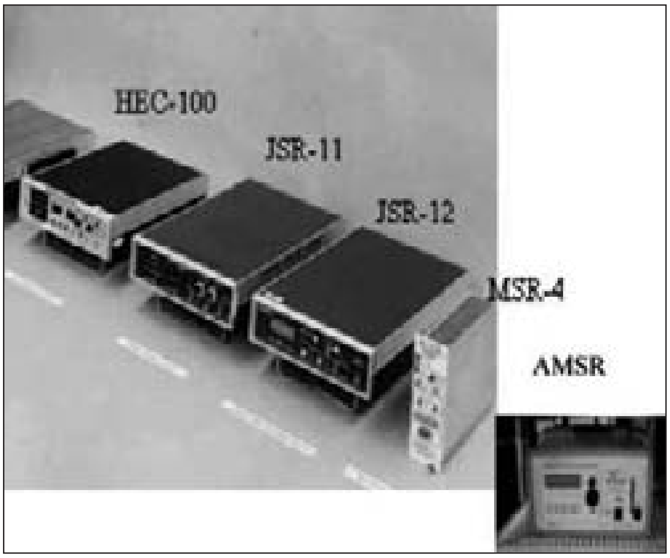


Figure 14. The Fuel Assembly Assay System (FAAS) installed at the output of the PFPF MOX fabrication plant in Japan to verify the product FBR fuel assemblies

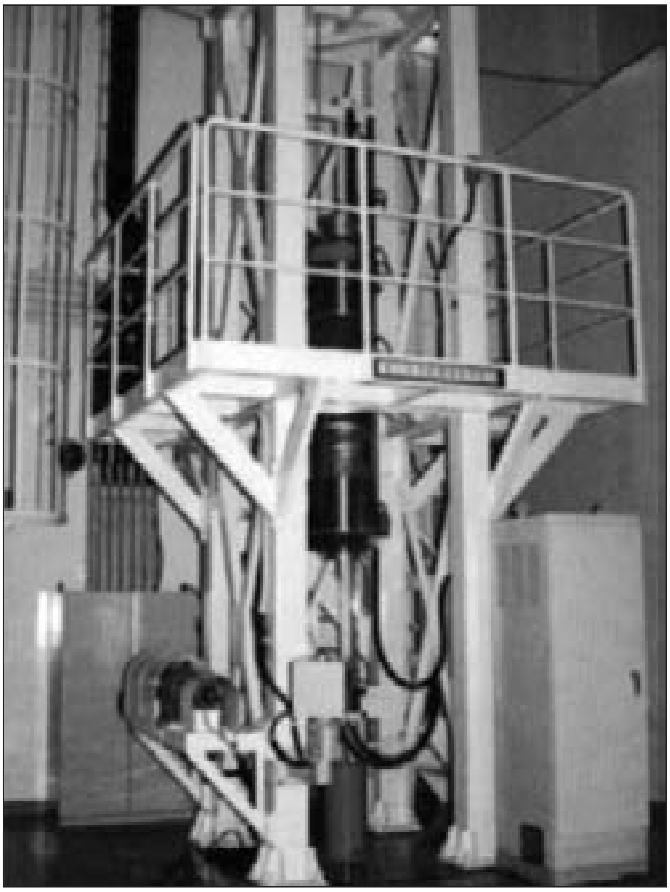


Figure 13. Plutonium Canister Assay System installed at the PFPF to verify input canisters of MOX (PCAS-1) and the transfer of canisters from the storage to the process area (PCAS-2). The IAEA system is integrated with cameras and direction of motion sensors on the walls with fully automated data collection software.

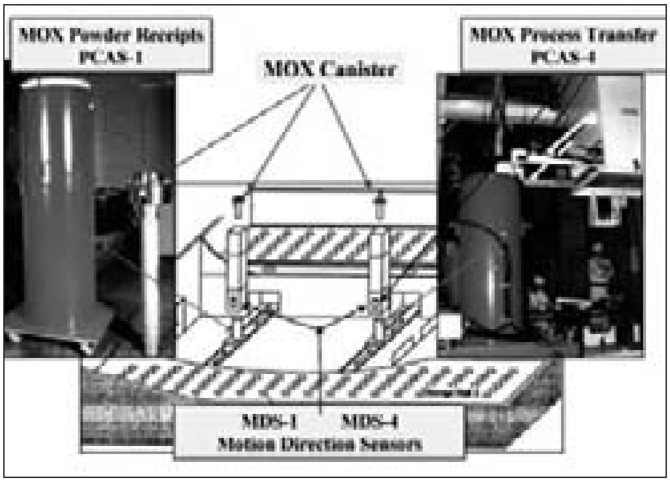
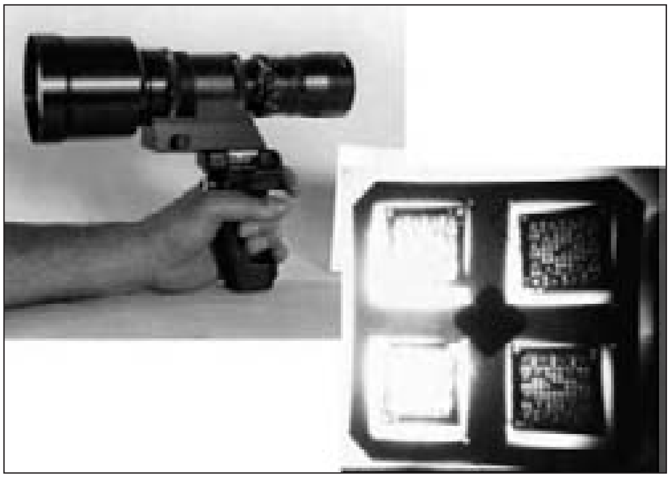


Figure 15. The original version of the CVD for the verification of the Cerenkov glow from spent fuel assemblies, more advanced versions of the CVD have been developed in recent years.



counters are designed as an integral part of the fuel handling system. The PCAS measures the MOX canisters during the transfer from the loading area to the storage area. The measurement is made while the canister is in motion demonstrating the integration of the NDA into the plant process. The plant robotics system automatically places 100 percent of the facility throughput into the two NDA systems for IAEA verification. These systems provided a major improvement in the effectiveness and efficiency of IAEA safeguards at nuclear production facilities. The measurements are more accurate than for portable NDA systems and the continuous data collection provides an important supplement to the containment and surveillance systems.

Figure 16. Underwater view of the Fork (FEDT) measuring the gross neutron and gamma activity from spent PWR fuel assemblies.

Figure 17. Alain Lebrun putting the AEFC into the spent fuel pool at the HIFAR reactor in Australia for an inspection verification of the spent fuel elements

Spent Fuel NDA

Most of the world's plutonium is in the spent fuel from power reactors and the IAEA recognized the need to verify spent fuel three decades ago. Because the fuel assemblies could not be accessed or sampled for DA, it was necessary to develop NDA methods. The spent fuel verification problem was intrinsically an international safeguards activity because the state could rely on physically security measures for the spent fuel. The following equipment has been developed for the verification of spent fuel assemblies:

- Cerenkov Viewing Devices (CVD and CKVD) (Figure 15)
- Fork Detector (FDET) (Figure 16)
- Passive Gamma Spectroscopy Systems
- Safeguards MOX Python (SMOPY) for light-water reactor fuel assemblies[11]
- Tomographic Gamma Scanning (TGS) for pins[12]
- Spent Fuel Discharge Monitors[13]
- Spent Fuel Coincidence Counter (SFCC) for FBR fuel and blanket assemblies
- Spent Fuel Package Assay Monitor (SPAM) for FBR fuel packages

In addition to power reactor fuel, there are more than a hundred research reactors worldwide that contain highly enriched uranium (HEU) or have the ability to produce Pu from the ^{238}U in the fuel elements or target materials in the reactor. The IAEA is currently developing equipment to verify spent fuel from the research reactors, and they have recently field tested the Advanced Experimental Fuel Counter (AEFC) at the heavy water moderated reactor (HIFAR) in Australia. The system measures the passive neutron coincidence rates and gamma emissions as well as active interrogation for the 235U content. Figure 17 shows the Alain Lebrun putting the AEFC into the spent fuel pool at the HIFAR reactor in Australia for an inspection verification of the spent fuel elements

There are numerous neutron and gamma measurement systems in use by the IAEA that are not included in this paper because of the lack of information and time.

IAEA Training for NDA

The development of NDA techniques and instrumentation meant a concurrent need for training in their application. Los Alamos conducted the first Fundamentals of NDA training course in 1973 presented to participants from the AEC and its contractor facilities. The same course was presented in 1974 to participants that included two IAEA inspectors. As other NDA courses were developed, beginning in 1975, IAEA inspectors participated in all of them as did inspectors from Euratom. In 1979, a second week of exercises was added to the Fundamentals course for 10 IAEA inspectors using only agency equipment and procedures. In 1980, the USSP mandated development of a special

Figure 18. (L) 1981 NDA course for IAEA inspectors. Robert Thiele (second from left) stayed an inspector for more than twenty-five years. (R) 1982 NDA course. Shirley Johnson has just retired from the agency and Alberto Barocas (middle) continues to assist the IAEA in retirement.

Figure 19. Both pictures were taken at an HEU PIV exercise at LANL. Reza Abedin Zadeh (L) and Olli Heinonnen (middle) present Deputy Director General for Safeguards. (R) Massimo Aparo (R) is section head for the Tokyo Field Office.

two-week training course for IAEA inspectors only (Figures 18 and 19). All new inspectors since 1980 have participated in this course which has changed over the years at IAEA request to reflect changes in IAEA safeguards and related NDA equipment. This course has now been presented forty-eight times between 1980 and 2007.

In the late 1970s, the IAEA began to formalize inspector training and eventually formed a Safeguards Training Section under Bernadino Pontes. This led to the development of the Introductory Course in Agency Safeguards (ICAS) that is taken by every new IAEA inspector shortly after their arrival in Vienna. This course now lasts almost three months, of which one entire month is devoted to NDA. For many years, these inspectors would attend the NDA course in Los Alamos shortly after the completion of ICAS. Now there is a period of eight to twelve months between ICAS and the LANL course.

Transformation of NDA to Installed Equipment

During the first fifteen years of NDA development for the IAEA, the focus of the effort was directed towards robust portable NDA equipment that could be carried to the inspection sites. However, during the twenty-one year period from 1986 to 2007, there has been an important technical shift in safeguards—from attended mode, hands-on materials inspection to installed, unattended, continuous-mode safeguards equipment. The IAEA and LANL designed and implemented the first of these continuous NDA data collection systems for the IAEA inspection at the PFPF MOX fabrication plant in Japan in 1987, in response to the need to safeguard the new generation of completely automated nuclear facilities. The savings in manpower time for the IAEA safeguards program was a factor of ten according to IAEA studies. However, many data authentication issues emerged during the use of IAEA equipment in an unattended mode within an operator's facility. These issues were resolved with both hardware and software developments. Because the radiation sensor data was being collected continuously, there was a natural development of the integration of the radiation measurements with the camera data to provide better containment and surveillance systems. Advanced techniques to integrate radiation data with surveillance images were developed, and data fusion became a major technical activity. The role of data collection software and analysis took a major step forward with the implementation of continuously operating safeguards equipment.

The interaction between the IAEA and Japan has resulted in significant developments in IAEA safeguards related to the unattended and automated use of NDA systems. The safeguards

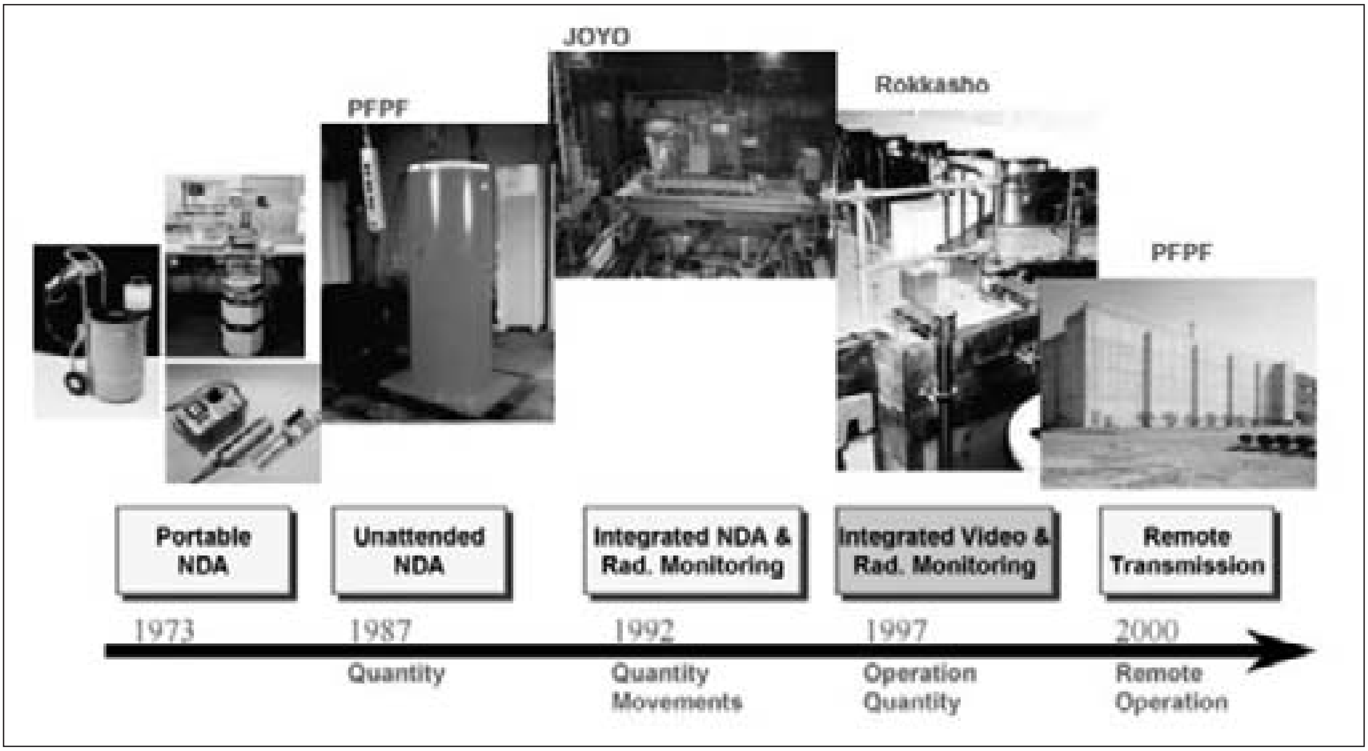


Figure 20. Illustration of the transition from IAEA portable NDA to installed, unattended NDA systems over a thirty-five year period

development activity in Japan has had special significance because Japan has constructed many of the next-generation nuclear facilities—such as automated reprocessing, MOX fabrication, and fast-breeder reactor facilities. The plants have sophisticated automation and high throughputs that require advanced safeguards approaches. The work in Japan led the way in the development of installed, unattended, continuous-mode-operation safeguards NDA equipment. These systems, illustrated in Figure 20, then led to an increase in the software and data networking functions, and now a major portion of the cost in a current safeguards system is for the software.

Future Directions for NDA

The amount of nuclear material under IAEA safeguards continues to expand worldwide and the role of NDA in the verification of the material will continue to increase. The application of chemical destructive analysis (DA) for the material verification has become more difficult with restrictive shipping regulations and the high cost of DA, especially for the high throughput facilities. There have been recent advances by the Euratom inspectorate at the Karlsruhe Transuranic Institute (TUI) and their On-Site Laboratories (OSL) to supplement and reduce DA with high-accuracy NDA for small *grab* samples. The accuracy of this type of NDA for Pu samples is the range of 0.2 percent to 0.4 percent. A similar technique is under development for the large processing facilities in Japan with an accuracy target of ~ 0.2 percent for the $^{240}Pu_{eff}$ by making use of the ENMC and carefully prepared calibration standards. The integration of NDA and DA for large processing facilities can be anticipated in the future.

For bulk samples that represent 100 percent of the throughput, the improved Pu Canister Counter (iPCAS) has been developed for NDA of the MOX canisters output at RRP. This system was recently calibrated by the IAEA and demonstrated a $^{240}Pu_{eff}$ measurement precision of 0.1 percent for a measurement period of thirty minutes. This more than satisfies the target accuracy of 0.8 percent to qualify as a "bias defect" verification for the IAEA. The bias defect capability for an NDA system is a major step forward for the IAEA, because it can apply to 100 percent of the throughput and the verification results are available much faster than for DA.

High accuracy for NDA systems is only possible with a close collaboration with DA laboratories to produce the standards. The path forward is likely to be a mixture of DA and NDA where the NDA can measure 100 percent of the throughput to eliminate sampling errors, and the DA is used on a subset of the samples to provide QA of the results and to provide the calibrations for the NDA.

Another future direction for NDA at the IAEA is measurement improvements for Pu holdup in the process glove boxes at MOX fabrication plants. It will be necessary for the IAEA to verify the Pu in process area in a timely manner during interim inspections. The Glove-box Unattended Assay and Monitoring

(GUAM) system is under development for this purpose. This system uses an array of ^{3}He tubes imbedded in the walls of the glove-boxes to measure the coincidence neutrons that are emitted from the Pu holdup inside the glove-box. The data is collected continuously in the computer (LIST mode) that provides the time and position of each measured neutron. This data is stored in a local computer for post analysis of the singles and coincidence events. The computer analysis makes it possible to reduce the high efficiency on the walls near a ^{3}He tube by means of data post analysis in the computer. The goal of the measurement is to get the same response from Pu holdup located anywhere inside the glove-box. The time history of the movement of Pu in and out of the process boxes is a significant improvement in the facility safeguards and provides the capability for process monitoring. Because the neutrons are emitted by the Pu and penetrate the containers, process equipment, the walls, monitoring of the neutron rate as a function of position provides a powerful safeguards tool.

For unattended NDA systems installed in an operator's facility, the authentication of the measured data is a challenge. Various techniques such as IAEA check sources, sealed enclosures and cabinets, and tamper-indicating conduits have been used in the past. The LIST mode data collection adds a new dimension for the indication of data tampering. For a case such as the GUAM there are eight separate data signal lines from each glove box leading to the LIST module and computer. The rates in each line are a function of the position of the holdup inside the box and the coincidence criteria gives cross linkage between each of the eight detectors. With the short time intervals and cross-coupled data (microsecond gates), it would be extremely difficult to falsify the correct response and time behavior. In effect, the added information of multiple channels, location, time, and cross-correlations provide a "self-indication" of possible data tampering.

Acknowledgements

The authors acknowledge the large number of dedicated staff members at the IAEA, Euratom, and Member State Support Programs (MSSP) who were instrumental in the development and implementation of the NDA systems described in this paper. The funding support from POTAS, DOE/NNASA, and the MSSP from other countries was critical in making NDA a key element for IAEA safeguards.

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JRC Scientific and Technical Support to IAEA Safeguards: Achievements, Lessons Learned, and Future Opportunities

Roland Schenkel
European Commission, Joint Research Centre (JRC), Brussels, Belgium

Abstract

This invited technical review article takes a look back and a look ahead in the area of research and development for international safeguards: some main developments, applications, the lessons learned, and the outlook for the future. Selected highlights of the past scientific and technical contributions of the European Commission's Joint Research Centre to the International Atomic Energy Agency (IAEA) safeguards inspections and technical support divisions are described: the development of the first large-sized metal spikes, the delivery of a laboratory robot designed for automatic U/Pu separations, the provision of safeguards training in PERLA (Performance Laboratory) and the use of the TEMPEST (Thermal, Electro-Magnetic, Physical Equipment Stress Testing) laboratory for IAEA. Current collaborations include the support activities to the Rokkasho Reprocessing plant, work on environmental micro-particle analysis, the delivery of nuclear reference materials and ultrasonic seals and the support in combating illicit trafficking of nuclear and radioactive materials. Based on these collaborations, an analysis is presented of the lessons learned and the areas for potential improvement, both under the support programme scheme and through enhanced international collaboration. Finally an outlook of future challenges and opportunities is given for S&T support to international safeguards and nuclear security issues covering aspects such as exploitation of satellite imagery and open source information, enhanced instruments for physical inventory taking in U facilities, innovative applications of containment and surveillance technologies, novel training courses for enhancing the nuclear inspectors observation and soft skills and issues of proliferation resistance of future nuclear energy systems.

Introduction:
The Nuclear Safeguards Agreement as a Basis for the JRC Support to the IAEA

The origin of the Joint Research Centre (JRC) is found under the Treaty of Rome, which foresees joint research in the nuclear field. In the 1960s, four research centers were established in the EU member states of Belgium, Germany, The Netherlands, and Italy. They focused on nuclear technology, nuclear safety, and safeguards, in particular in support of the Euratom inspectorate.

Figure 1: Collection of reference materials

In 1981 the JRC began to apply its experience in nuclear safeguards in support of the International Atomic Energy Agency (IAEA). This was formalized with the signature of the Nuclear Safeguards Agreement on May 7, 1981, by W. Haferkamp, the European Commission Vice President in charge of External Relations, including Nuclear Affairs, and the IAEA General Secretary S. Eklund.

Historical Examples of JRC Support to IAEA

Reference Materials for Accurate Measurement of U and Pu Isotopic Content

A major improvement in the measurement of uranium and plutonium isotopic content of dissolved nuclear fuel—a critical point in the safeguards control of fissile material in the fuel cycle—was the development of metal spikes of enriched uranium and plutonium at Central Bureau for Nuclear Measurement, as the JRC institute at Geel, Belgium, was originally known. The dilution stages necessary before measuring the fissile material content by conventional isotope dilution mass-spectrometry was long recognised as the weak link in the handling and preparation of samples.

Figure 2: ITU chemical separation robot installed in a glove box

The provision of a large spike, originally developed in metallic form, was the solution for this problem. Although metal spikes had a number of advantages in handling and in the chemistry, they have now been superseded by the "large-sized dried spikes" that are produced at present in considerable numbers at the Institute for Reference Materials and Measurements (IRMM). The importance of isotopic reference materials and spikes for isotope dilution was recognized early in the EC-IAEA support program[1] and the JRC has been a major developer and provider of these materials for the IAEA. The mixed plutonium isotope set (^{239}Pu + ^{242}Pu: IRMM-290), for example, was prepared and certified in the early 1980s and remains a foundation stone for accurate measurement of Pu by mass-spectrometry. Around the same time, a set of uranium isotopic mixtures in UF_6 and uranium nitrate forms were prepared and certified, which are the basis worldwide for measurements of uranium isotopic abundances in depleted to low-enriched uranium (Figure 1).

The Laboratory Robot

In 1990 a Robot Glove-Box was delivered by JRC's laboratory at the JRC Institute for Transuranium Elements (JRC-ITU) to the IAEA Safeguards Analytical Laboratory (SAL). The laboratory robot consists of a sampling station and a chemical separation unit (Figure 2) and automates the preparation of sample solutions with dissolved fuel. Uranium and plutonium are separated automatically from the sample matrix with the necessary degree of purity so that their concentrations can be measured with high precision by Isotope Dilution Thermal Ionization Mass Spectrometry. The Institute for Transuranium Elements (JRC-ITU) has had experience with such automated systems since its development of a first robot design based on a Zymark laboratory robot for liquid-liquid TBP extraction of U and Pu.[2] The automated system designed for the IAEA SAL was based on a robot for liquid-solid phase extraction of U and Pu using trioctylphosphine oxide, which increased the reproducibility and sample throughput while reducing the radiation dose to personnel. Similar automated separation systems for U and Pu have been further applied to the two Euratom On-Site Laboratories at Sellafield and La Hague.[3]

Figure 3: The PERLA Laboratory for non-destructive assay techniques

The PERLA Laboratory

The Performance Laboratory PERLA of the Institute for Protection and Security of the Citizen (IPSC), established in 1989 to assess the performances of non-destructive assay (NDA) techniques, has from the beginning supported the IAEA inspectors with training and equipment validation. Equipped with a large range of nuclear standards and instrumentation, PERLA has enhanced the analytical capabilities of IAEA inspectors by providing performance evaluation and calibration of both hardware and software of NDA instruments, development of new NDA instrumentation and methodology, and inspector training (Figure 3). Several international benchmark exercises have been held in PERLA to evaluate and compare the capabilities of NDA instruments, such as passive and active neutron counting, inclusive multiplicity counting and high-resolution gamma spectrometry for Pu isotopic measurements. In 2001 the IAEA Workshop on "Assessment of Verification Methods for Excess Nuclear Material from Disarmament" took place at PERLA and formed part of the Trilateral Initiative to test supervision methods for stored nuclear warheads.[4,5] American and Russian scientists demonstrated NDA techniques for verifying excess weapon

Figure 4: ALIS Surveillance System

Figure 5: Rokkasho Reprocessing Plant (RRP)

nuclear material at its return to the civil cycle while defining information barriers.

The TEMPEST Laboratory

In order to address the performance and reliability testing of safeguards equipment for the Euratom and IAEA inspectorates, the Thermal, Electro-Magnetic, Physical Equipment Stress Testing laboratory TEMPEST was established in 1995. Standardised test methods, procedures and protocols have been set up, which are documented in many technical notes.[6] Between 1999 and 2003 TEMPEST performed thirty complete tests for the inspectorates. Typical devices that were tested include the radio-frequency transponder based fibre-optic loop seals,[7] the All-in-One-System (ALIS) camera surveillance system (Figure 4),[8] the digital gamma spectrometer,[9] and the Electronic Optical Sealing System.[10]

Figure 6. HKED-PNCC measurement station for input solution analysis at Rokkasho

Current Examples of JRC Technical Support to IAEA

Contribution to IAEA Safeguards in the Rokkasho Reprocessing Plant (RRP), Japan

With the construction of the RRP, on photo (Figure 5), the IAEA faced for the first time the need to set up a complete safeguards inspection regime in a large commercial reprocessing plant of a non-nuclear weapons state. JRC, with its expertise in supporting Euratom for inspections at the large reprocessing plants of Cogema in La Hague and of BNG in Sellafield, has for that purpose provided services to the IAEA to establish and operate the safeguards on-site laboratory at Rokassho and in-design information verification and process monitoring.

Support for the Analytical Laboratory On-Site at the RRP

The two basic techniques used to measure the uranium and plutonium content in samples taken from the input accountancy tank are isotope dilution mass spectrometry (IDMS), and K-edge densitometry and X-ray fluorescence (XRF) analysis combined in the so-called Hybrid K-Edge Densitometer (HKED).[11,12]

A major step forward for accurate and unbiased mass spectrometry measurements by IDMS was to minimize the corrections needed for mass fractionation. This has been achieved with the Total Evaporation Technique developed at ITU in the mid-1980s.[13] This technique has been also adopted by the IAEA. With the total evaporation technique, together with the use of the large-size dried (LSD) spike introduced by the EC Institute for Reference Materials and Measurements (IRMM) in the 1990s, it is now possible to achieve a relative measurement uncertainty close to 0.1 percent for the determination of the uranium and plutonium concentration in reprocessing input solutions.

Although it does not provide the ultra-high accuracy of IDMS, the HKED technique offers the great practical advantage of operational simplicity and speed of analysis. In fact, it has

Figure 8: Automatic detection of differences after 3D scan

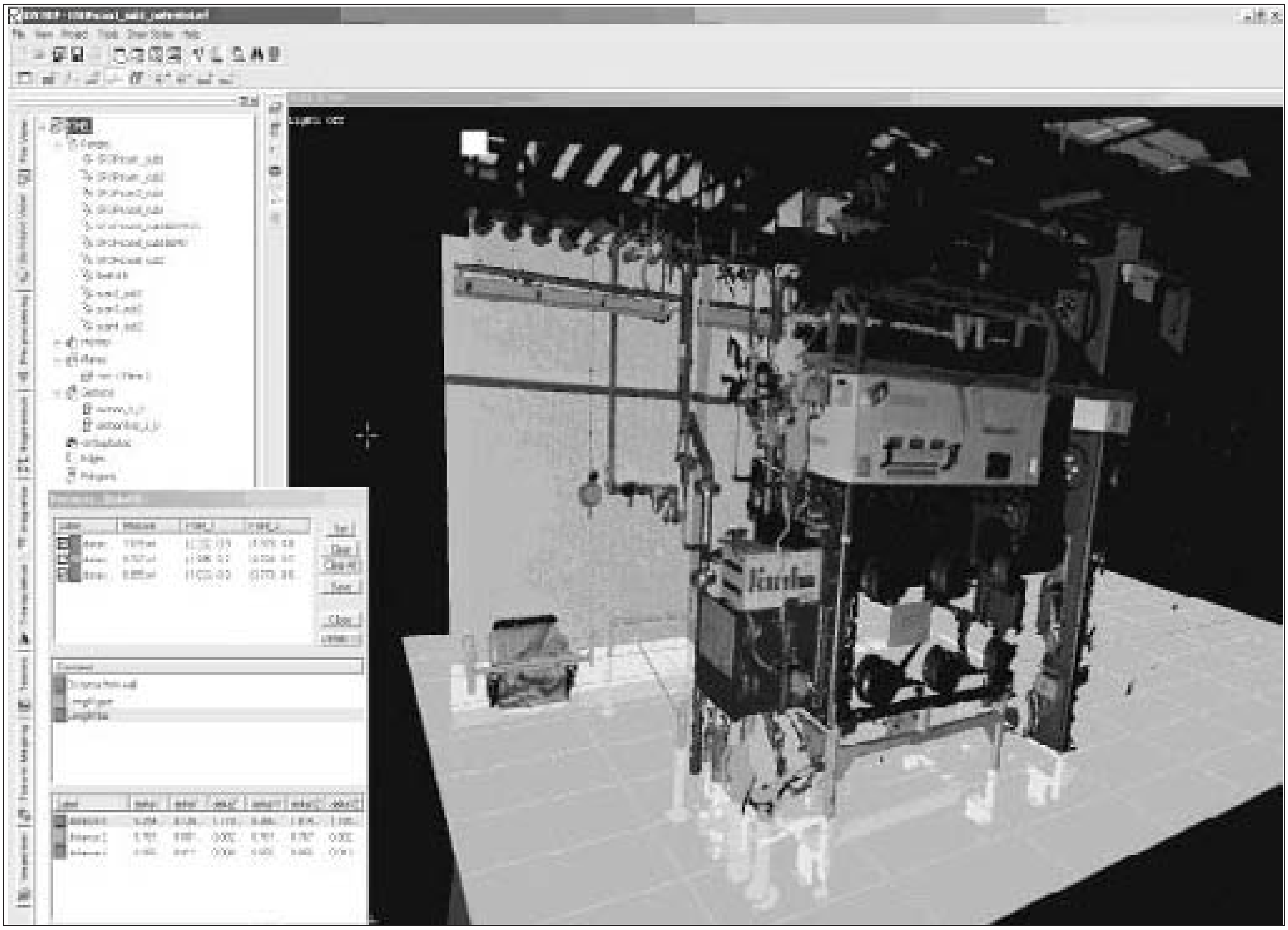
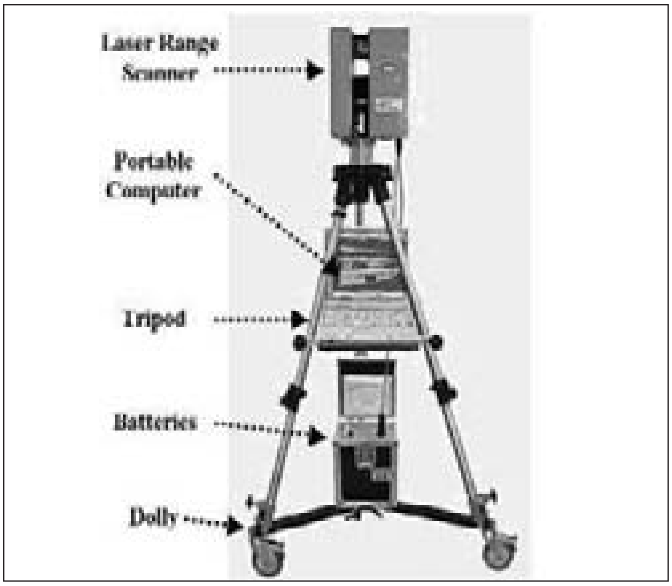


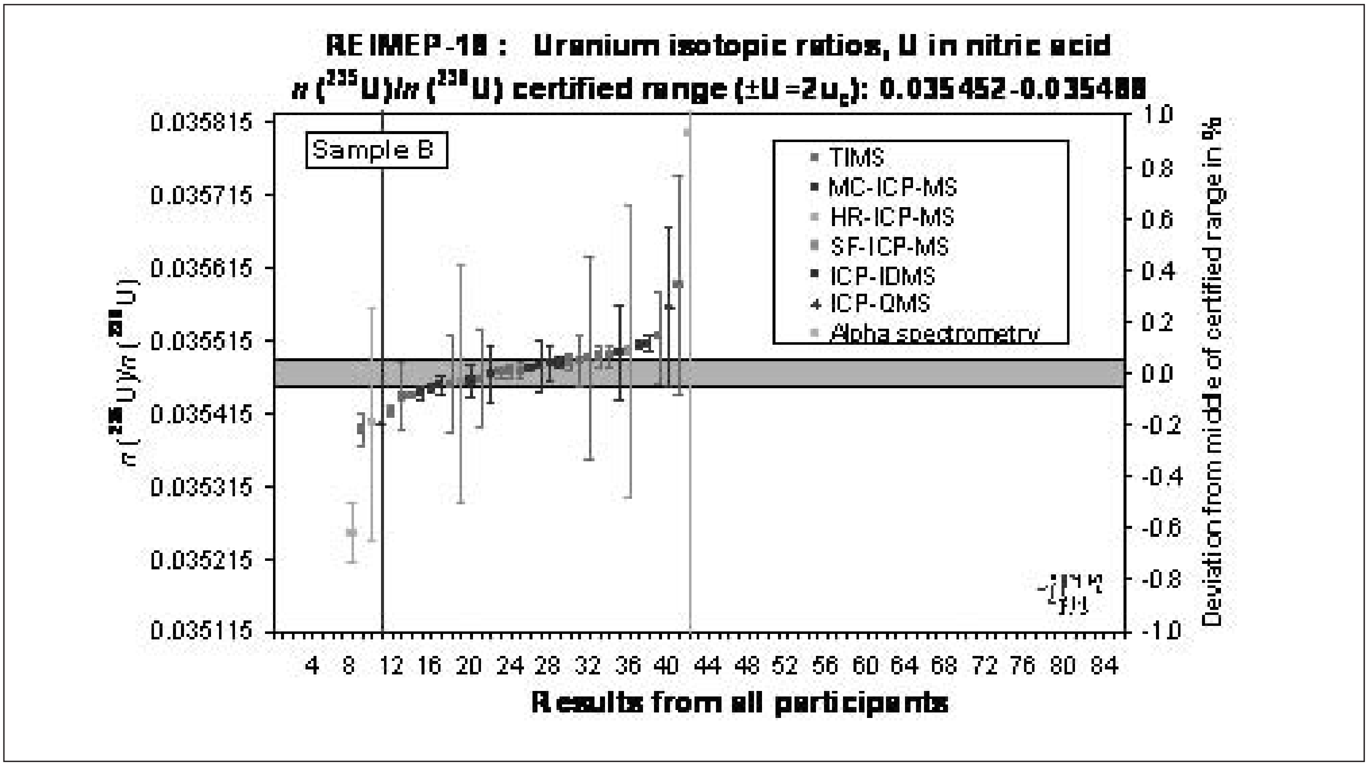
Figure 7: Laser Range Scanner



become the safeguard workhorse in reprocessing plants for 100 percent control of all input batches. ITU has supported the IAEA with the installation of two HKED systems at Rokkasho, one being attached to a shielded hot cell for verification measurements on the highly radioactive input samples, and another one installed at a glove-box for the analysis of product samples. ITU delivered the core HKED mechanical assembly with a patented sample changer for enhanced measurement automation and sample throughput.

A novel feature added on request of the IAEA to the HKED for input solution analysis at Rokkasho is the incorporation of a passive neutron coincidence counter (PNCC) for the simultaneous measurement of the ^{244}Cm content in the input solution, following previous proposals of integrating curium measurements into a safeguards system for reprocessing plants as a means for plutonium follow-up in waste streams.[14] The specially designed neutron counter, closely fitting into the HKED assembly, was built and tested at ITU prior to the installation at Rokkasho. The combined HKED-PNCC measurement station for reprocessing

Figure 9: Example from an inter-laboratory comparison exercise in mass spectrometry analysis



input verification measurements is shown in Figure 6. An elaborate software for the evaluation and control of the ^{244}Cm measurements in the HKED station will be shortly made available to the IAEA.

Design Information Verification and Process Monitoring at the Rokkasho Reprocessing Plant

The IAEA was provided in Rokkasho with a 3D laser range finder (Figure 7), which was used by the JRC-IPSC to create an accurate 3D reference model of the plant. This reference model can then be compared with any other 3D model, scanned at a later time during different design information verification (DIV) inspections. The software developed at the JRC identifies directly all differences between the 3D models (Figure 8), and supports the inspector's DIV. In addition all distances, such as tank size, pipe lengths and diameters, can be interactively computed for inspection's annotations.[15, 16] As a complement to the scanning of external geometries, JRC-IPSC provided also assistance to tank calibrations, in particular of the input accountancy. Process monitoring tools have been developed by JRC and IPSC staff are currently providing consultancy to IAEA in the area of solution monitoring.

Other Examples of Current Collaboration and Support

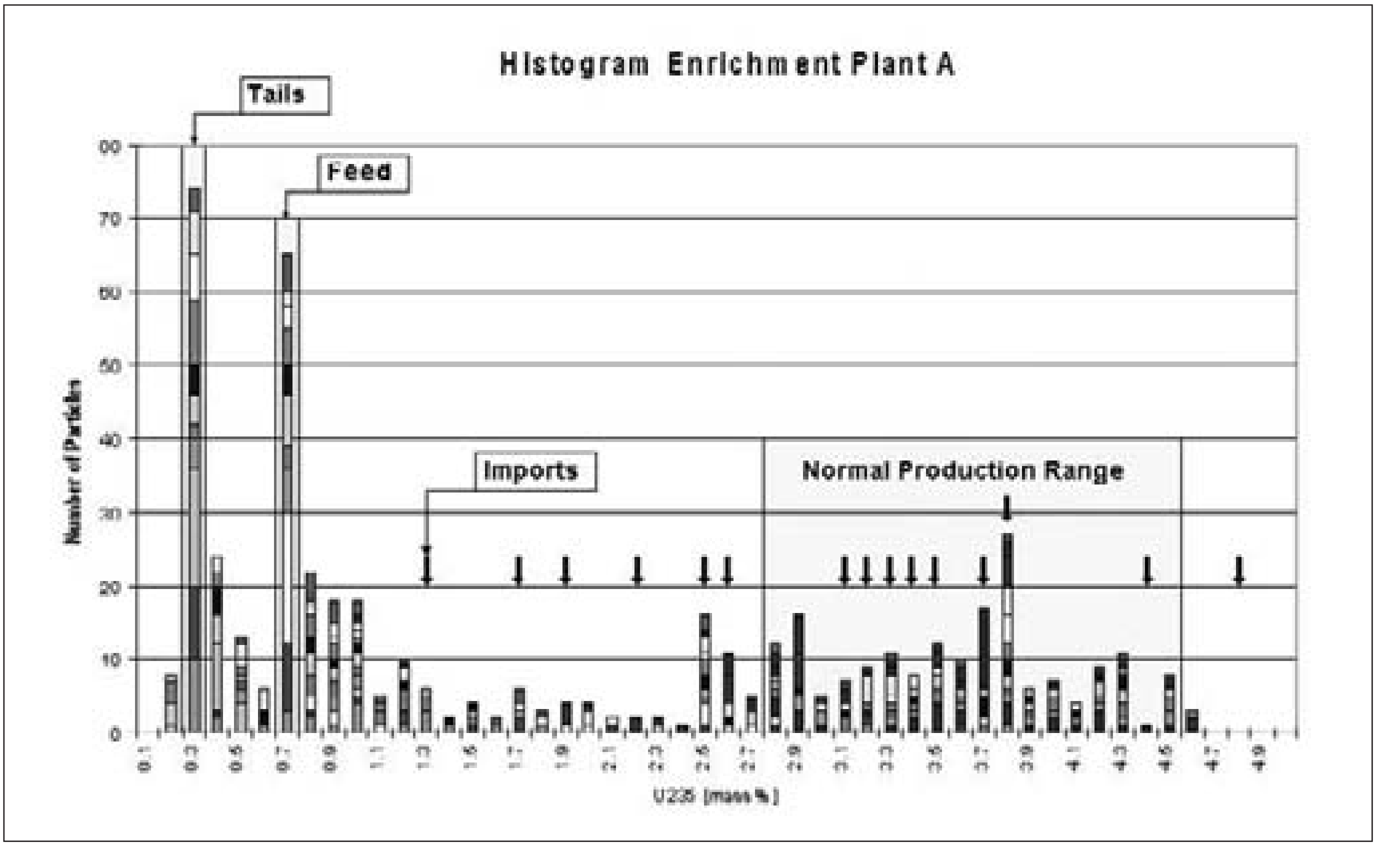
Nuclear Reference Materials and Measurement Improvement

The JRC laboratory at Geel supports the need for continual improvement of measurements in the nuclear field with the interlaboratory comparison exercise REIMEP for nuclear measurement laboratories (Figure 9)[17] and the continual development of reference materials. JRC-IRMM was major proponent of the International Target Values and these have gone through a major update under the auspices of the IAEA.

Environmental Sampling and Analyses of Nuclear Material

In order to detect undeclared nuclear activities, the safeguards authorities need to apply the most advanced techniques available. In particular the application of the environmental sampling methodology was enforced in the late nineties by the Additional Protocol. One of the major techniques in environmental sampling is particle analysis performed on dust samples from surfaces of equipment or infrastructure inside buildings, collected by safeguards inspectors using cotton swipes.[18] The JRC-ITU has been active in this field for several years, and is an early member of IAEA's Network of Analytical Laboratories (NWAL). The JRC-ITU uses predominantly a technique for these measurements which is based on Secondary Ion Mass Spectrometry (SIMS, see Figure 10). The JRC is increasing its efforts to strengthen its technical capabilities, in particular the improvement of the measurement precision of minor isotopes (^{234}U and ^{236}U) is important.

Figure 10: Swipe samples from an enrichment facility were measured by SIMS. The figure shows the number of micro-particles as a function of the U-235 content. The product range has an enrichment between 2.8 and 4.6 percent.



These isotopes can provide essential information about enrichment facilities and the type of feed materials used. Cooperation with IAEA has recently been extended beyond the particle detection work to the analysis of bulk nuclear material. One example is the determination of trace elements in bulk uranium samples.

Ultrasonic Seals

New sealing systems for dry and underwater storage were recently developed at the Joint Research Center. A new sealing system for CANDU reactor spent fuel bundles, to replace the AECL ARC seal, was developed following IAEA requirements. The new bolt for underwater sealing is adapted from the design of the sealing bolts already used in the La Hague reprocessing plant. The design was revised in order to comply with the CANDU interface requirements. A first series of bolts with the new reading head and data acquisition system are already used for a field trial in Cernavoda. A set of fifty seals and a full reading system are being produced for a vulnerability assessment. A new sealing system for dry storage containers was also developed. This new bolt is still based on ultrasonic reading but with increased anti-tampering features to cope with the easier accessibility of dry storage. A doubly correlated identity makes tampering extremely difficult.

Support to Combating Illicit Trafficking of Nuclear Materials

Since the first reported cases, the JRC has been involved in the fight against the illicit trafficking of nuclear materials in collaboration with major international actors in the field, in particular the IAEA and the Nuclear Smuggling International Technical Working Group (ITWG). The JRC developed jointly with ITWG a Model Action Plan (MAP) to respond to seizure of nuclear materials.[19] In-field exercises in testing the implementation of the MAP have been carried out (Figure 11) and will be continued. The MAP is currently being issued as a guideline by the IAEA.

In parallel, the JRC has developed the scientific and technical expertise to support the nuclear forensic investigations of confiscated material. A nuclear material database and advanced analytical technologies have been developed which can be applied to obtain clues on the origin of the seized material, its intended use and the possible trafficking route. The trace element content of nuclear material will play an increasingly important role for the origin attribution. Information sharing between relevant authorities is obviously another important means to support illicit trafficking investigations. In the 2006 meeting of the ITWG various options for information sharing were discussed, including the creation of a *super* database containing information about other

Figure 11: Exercise on seizure of nuclear material following the model action plan

Figure 12: Satellite image of the partially covered enrichment facilities in Natanz (Iran)

organizations' databases on illicit trafficking and nuclear forensics. This decentralized approach may be easier to implement than a single centralized database.

Substantial technical support was provided to the IAEA in the frame of the CRP "Improvement of Technical Measures to Detect and Respond to Illicit Trafficking of Nuclear and other Radioactive Materials." The "Technical/Functional Specifications for Border Radiation Monitoring Equipment" as set up by IAEA specialists were practically tested for many different measurement devices—both hand held and fixed installed systems—in the PERLA laboratory and outside, using real nuclear material. Following this experimental campaign in 2003 the specifications were revised and could come into force. Another contribution to the project was the delivery of three collections of gamma radiation spectra of nuclear materials and industrial radiation sources, registered with Ge, NaI, and LaBr3 detectors. These spectra are available to instrument developers, who cannot do measurements on such material but need them for their development work.

In order to reduce the innocent alarm rate of border monitors and to detect nuclear material concealed in NORM (Naturally Occurring Radioactive Materials) IPSC has recently started an activity on the characterization of NORMs and of their transport conditions in order to study methods allowing the discrimination between NORM and man-made radioactive sources and nuclear material. The techniques under study are: secondary screening with high resolution gamma spectroscopy, use of a broad energy response analysis of plastic scintillators (nuclear materials emits in the low energy, technological radioactive sources in the medium energy and NORMs in the high-energy region), and analysis of space/time profile of the portal response during the container transit in order to discriminate distributed NORMs from concentrated radioactive/nuclear materials.

Quite recently, a Working Group dedicated to border monitoring activities has been created jointly with the IAEA, to coordinate the activities in the field of the major international support programs and in particular those from Europe and United States. In the same field JRC is organizing, together with the IAEA, training sessions on a regular basis for law enforcement services involved in the fight against illicit trafficking, sharing resources and information to implement an international integrated response. Yet another domain with potential for enhanced cooperation is the testing and qualification of measurement equipment for radioactive substances. Finally, through the Joint Actions, the European Union is participating to the nuclear security funds of the IAEA and the JRC provides its expertise for the assessment of the corresponding program.

Lessons Learned from the JRC Support to IAEA

During the twenty-five years of the European Commission Support Program (EC-SP) to the IAEA several lessons have been learned.

- Safeguards, as any other security application, is an area in need of continuous R&D work. This is the only way to ensure proper protection with constantly changing threat scenarios. In support of the Additional Protocol, e.g., a series of new techniques was developed, some relying upon competences not previously present in the nuclear safeguards community (like satellite image interpretation and open source data mining). A challenge in this respect is mutual education between different disciplines (e.g., image specialists and nuclear engineers). This is currently being pursued in several new tasks of the EC-SP to the IAEA.

Figure 13. View of the new L-edge densitometer for uranium element assay

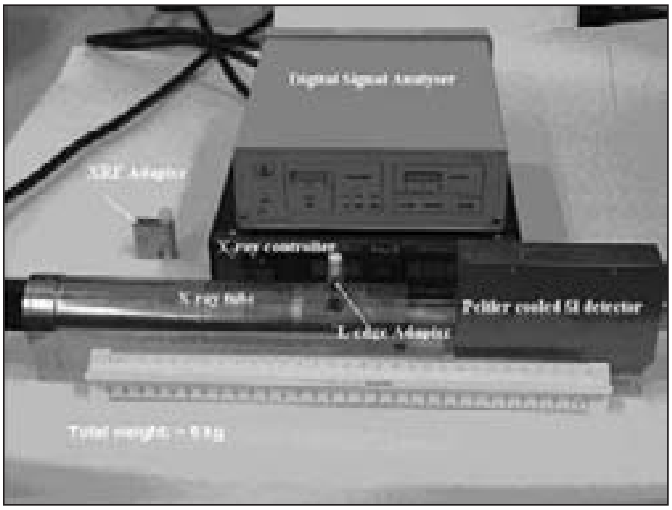
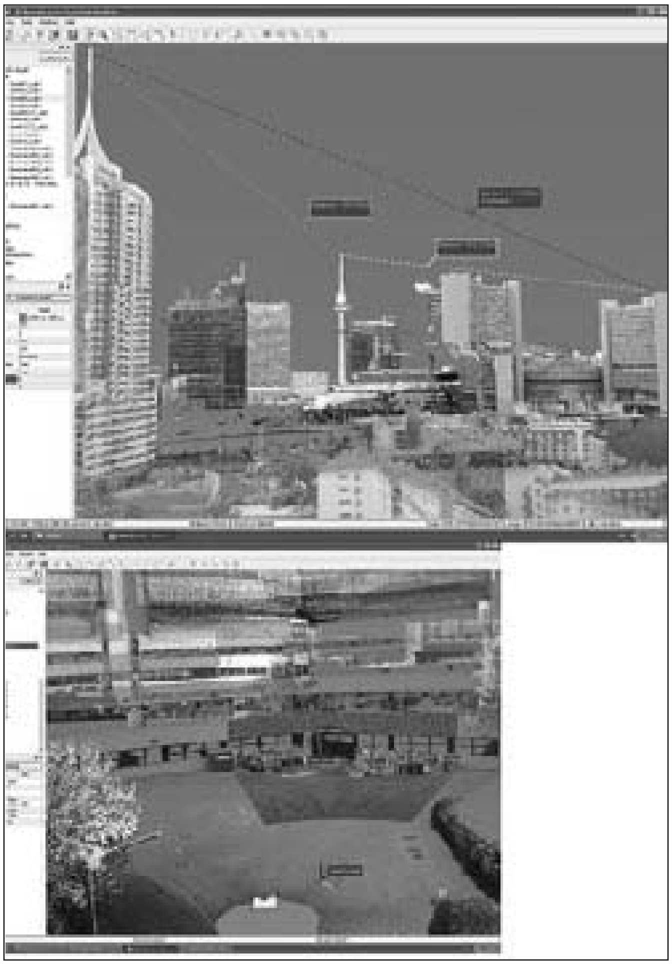
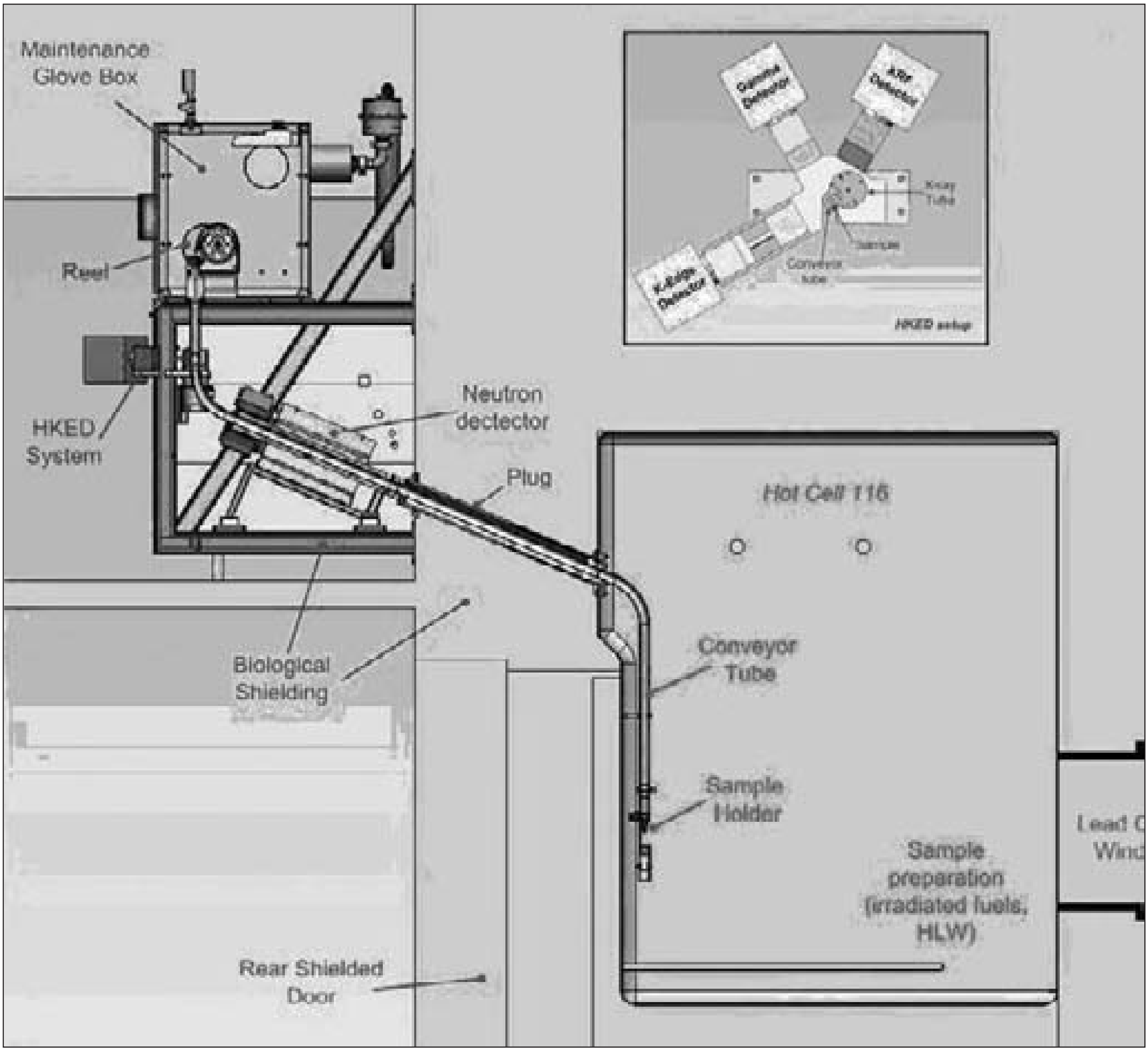


Figure 14. 3D model of the Vienna International Centre with change recognition features highlighted



- A prime concern for R&D support is the risk that highly scientific/technical and possibly complicated solutions are developed that do not always address properly the end-user (inspector) needs and boundary conditions. It is thus essential that researchers and developers have access to and information about the in-field conditions of the inspection work and that they receive feedback on the user-friendliness, reliability, and practicality of the developed instruments and methodologies. A good coordination is required between the research labs, the technical support departments and the inspectorates and it is highly recommendable to foster mutual exchange of personnel (e.g., in field assistance to inspections of researchers and vice versa direct inspector input in the establishment of research priorities and/or evaluation of research results).
- Nuclear safeguards is a highly specific application area. Authorities cannot depend solely on market forces as development and deployment costs would be prohibitive. Safeguards R&D becomes mainly a multidisciplinary systems integration area. For the purposes of both economizing on on-site inspection costs and increasing the inspection efficiency, automation, robotization, and intelligent systems for multi-signal processing are being further developed.
- This trend for integration is confirmed by the perception that enlarged systems will play an increasingly useful role in safeguards, extending the R&D focus from system components to systems' architecture and analysis including wide and secure data access and transmission.
- As a logical consequence of both the fiftieth anniversary of Euratom and of the IAEA in 2007, the first generation of pioneering scientists, engineers and nuclear safeguards inspectors have retired from their professional activities and a new generation of specialists needs to be formed. Maintaining and further generating knowledge and attracting young people to a professional career in this area is a challenge where JRC in close collaboration with IAEA seeks to make a contribution. Both education for academic students[20] and continued professional training are therefore required.
- JRC's work (including the EC-SP) following the political orientations of the European Union concerning the fight against nuclear proliferation and WMDs, meets IAEA's needs and expectations in many developments. The concerns on non-state actors requests attention for new priorities such as in the area of import/export control of dual-use items and technologies.
- JRC's success in the EC-SP comes from several factors of which one of the most important is a continuous and direct dialogue with IAEA staff. This has permitted a good understanding of the global threats and the specific, operational needs of IAEA inspectors. Given the application niche of safeguards, the EC-SP has collaborated with other MSSPs in

Figure 15: Outline of a multipurpose NDA assay station for pyrochemical process samples installed at a hot cell facility at JRC-ITU.



many occasions. This cooperative and complementary work has encouraged a geographically distributed spirit of community where participants from different organisations and cultures work together towards a common goal. The need for enhanced cross-support program collaborations is one of the major recommendations for a further improved collaboration between JRC and IAEA.

New Collaborations Between JRC and IAEA and Future Opportunities

JRC Observatory for Nonproliferation Compliance

As a service to the European Commission Directorate General External Relations and both the Situation Centre and WMD monitoring centre of the European Council, JRC developed so-called "nuclear country profiles" for a series of countries. Based upon analysis of both open source information and satellite images the JRC has gained competence in monitoring the evolution of the fuel cycle and nuclear R&D activities for individual states (or regions). Use is made of an in-house developed innovative media monitoring system that includes strengthened web mining, language tools and analysis, keyword identification and document clustering. This information is combined with open source data on the status of installations, import of materials and technology, commercial circuits used, scientific and technical capabilities, satellite imagery and person identification or tracking (Figure 12). On the satellite images, JRC collaborates with the European Council Satellite Center in Torrejon. Web searches, geographic information systems, and techniques for open source information retrieval and analysis, represent a future area for technical support with IAEA.

Innovative Infield High Accuracy Measurements in U Facilities

COMbined Procedure for Uranium Concentration and Enrichment Assay (COMPUCEA) describes both a method and an instrument used for timely on-site verification measurements in uranium fuel production facilities during joint Euratom/IAEA inspections. With the primary objective of producing a simplified instrumental variant better adapted to the requirements for in-field use, a second generation of COMPUCEA equipment has been recently developed at ITU.[22] The new equipment can be considered as a small analytical laboratory "out of the suitcase" for mobile use. The core of the second generation of COMPUCEA is a compact L-edge densitometer for uranium element assay (Figure 13), and an enrichment measurement part with the new type of lanthanum bromide scintillation detector for room-temperature operation (ready-to-use equipment). Validation measurements as requested by IAEA are currently being performed with the new equipment.

New Developments Under Containment and Surveillance Applied to Nuclear Security

In parallel to the developments for the laser-based design information verifications systems (as presented in the Rokkasho section above) a series of additional applications are currently under development (in different stages of validation) and could find both interest from the IAEA and national authorities. First is the creation of baseline information (i.e., design, dimensions, equipment) for installations and sites (re)entering a safeguards regime. This baseline is to be used as a reference for future inspections and verifications. The technologies to be used are based on the integration of 3D laser scanning for accurate dimensional measurements, photography for visual documentation and radiation measurements. These technologies can be used both indoors and outdoors. Successful experiments have been made, e.g., at Vienna International Center (Figure 14). In view of enhanced nuclear security, this technology can be envisaged also for urban radiation modelling, to create the baseline of radiation sources in large vulnerable areas, such as urban environments. The big advantage is to decrease the number of false alarms in real emergency situations as most legal sources are known and already mapped. A second new application is the accurate 3D Relief Surface modelling for container self-authentication. It has two applications: one is to complement conventional sealing allowing for the verification of container integrity or 3D surface changes relative to a reference template (fingerprint). The first foreseen application is the container and weld verification on MOX fuel transportation flasks. The second application is the self-authentication or unique identification by using the native unique 3D surface structure of the cylinders to recognize and authenticate them. This is planned to be applied for the unique identification of UF_6 cylinders at enrichment plants.

For the optimized positioning and improved planning of multiple sensors (e.g., surveillance cameras or radiation sensors) in facilities under safeguards, use can be made of graphical simulation tools. Technologies derive from virtual reality including graphical modelling, physics-based active behavioral modules (for sensor modeling). The same graphical tools (and models) can be used for training, vulnerability assessment and for the visualisation of remote monitoring data both online (i.e., real-time) and offline (i.e., time deferred or in archive).

Novel Training Courses for Enhancing the Nuclear Inspectors Observation and Soft Skills

In close collaboration with both IAEA and DG TREN, IPSC is participating in the development of a dedicated training with respect to the Additional Protocol and Complementary Access. A first course was organized in March 2007. During this course several complementary access exercises are simulated in some of the nuclear facilities: spent fuel pond (visit), reactor, hot cells, and tritium laboratory. The goal is to test and improve the investigative skills and also to focus on the observational, communication, negotiating, and team-building skills currently required of nuclear inspectors in the detection of undeclared activities. To do that a modified AP site declaration is used with deliberate missing or wrong information. The inspectors are challenged to discover the inconsistencies and the possible indicators of clandestine nuclear activities. The JRC-Ispra provides operators who are briefed on role playing activities to assist in the challenges, particularly with respect to the "soft skills" required from the inspectors in completing their tasks. The agency has highly appreciated the first workshop that could become permanently a part of the IAEA training scheme. The added value of this training lies both in the relevance and variety of the sites to be inspected and in the tools (or lack of those) available to execute the complementary access. Such tools are both technical and soft skills, both of which are evaluated on their value and need for further development.

Issues of Proliferation Resistance of Future Nuclear Energy Systems

In order to streamline the research and to prepare the nuclear energy systems of the future, international initiatives are working on the so-called Generation IV nuclear energy systems, which should be ready for deployment in 2020-2030. The European Commission represents Euratom in the Generation IV International Forum (GIF) and the JRC is actively involved in several GIF issues. Based on the criteria of sustainability, economics, safety, and reliability, and proliferation resistance and physical protection (PR&PP) six reactor concepts have been retained by GIF for further consideration.[23] These nuclear energy systems will have to demonstrate their proliferation resistance based on both intrinsic features, such as, fuel composition, and extrinsic measures, such as the deployment of international safeguards. JRC-IPSC, together with the IAEA, is actively contributing to the PR&PP Expert Group of GIF developing an evaluation methodology for PR&PP aspects of GEN IV systems.[24] An issue also addressed by the PR&PP group is that of the safeguardability of the reactor concept at the design stage, so that more effective and efficient safeguards measures can be implemented. In this area JRC also contributes to the IAEA-driven International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) which addresses this issue of proliferation resistance and physical protection robustness in parallel and synergy with GIF.[25]

Most of the future GEN-IV reactors are expected to operate in a fully closed fuel cycle, in which the actinides must be recovered from appropriate reprocessing units. At present, two reprocessing routes, based on advanced aqueous and on pyrochemical processes, are considered. It can be anticipated that physical verification measurements as an undisputed objective safeguards tool will continue to play an important role among the future safeguards measures. Because of the very nature of the nuclear materials encountered in the future fuel cycles, straightforward non-destructive measurement techniques will gain increased importance for the respective safeguards verification measurements. JRC is currently pursuing substantial research work on the future reprocessing processes as well as on the development of appropriate nuclear fuels for the future GEN-IV reactors and transmutation facilities. Along with this research work appropriate non-destructive assay techniques are being developed and tested for the control and assay of process samples from the respective pilot test facilities, and for the assay of the special fuel specimens produced for the new fast reactors. As an example, JRC-ITU is currently setting up a multi-purpose nondestructive assay station for the direct measurement of actinides in process samples originating from its pyrochemical test facility.[26] The NDA station outlined in Figure 15 incorporates a variety of non-destructive radiometric assay techniques (KEDG, XRF, HRGS, NCC), which can be employed individually or in combination, depending on the assay requirements.

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Safeguards Sensors and Systems: Past, Present, and Future

Keith Tolk, Dennis Mangan, Don Glidewell, and John Matter
Sandia National Laboratories
Albuquerque, New Mexico, USA

Julian Whichello
International Atomic Energy Agency
Vienna, Austria

Abstract

Sensors are a vital and critical element in measuring and monitoring systems for technical safeguards approaches. Safeguards sensors have evolved from standalone analog devices to integrated digital systems. Safeguards sensor technologies are a niche market that has been driven by other commercial and military demands and applications. Developers and manufacturers have successfully adapted technologies of the day to be effective products for safeguards applications. In this paper commemorating the first fifty years of the International Atomic Energy Agency and its role in the peaceful uses of atomic energy and international safeguards, we highlight the evolution of sensor technologies applied to international safeguards. This history began with the use of cameras and seals for containment and surveillance to maintain continuity of knowledge on safeguarded materials and activities. The current international safeguards norm is based on a combination of onsite verification measures and unattended and remote measurement and monitoring systems. The near-term need for detection of undeclared nuclear materials, facilities, and activities will likely be addressed by the engineering development of several novel technologies. The long-range development of safeguards sensor systems will be shaped by research in materials, computing, and communication technologies.

Introduction

On the fiftieth anniversary of the establishment of the International Atomic Energy Agency (IAEA), it is important and instructive to consider the essential role that technology, particularly sensors, has played in international safeguards. Sensors have been used in all safeguards applications, such as inspections and material measurements for verification of member state declarations, and unattended monitoring during inspector absence to maintain continuity of knowledge.

Another paper in this special commemorative issue of the *Journal of Nuclear Materials Management (JNMM)* addresses radiation and other nuclear material measurement sensors. The focus of this paper is on the sensors, data security, and sensor systems used in unattended monitoring systems for containment and surveillance (C/S) of nuclear materials and associated activities, and a new generation of novel technologies that is targeted for the detection of undeclared activities in both declared and undeclared locations.

It is not surprising that safeguard sensors are technology-driven, since the international and domestic safeguards market is much smaller than the vast civilian and military markets. It is also not surprising how much the safeguards sensor technologies have evolved since the beginning of IAEA safeguards, considering the major changes in the commercial sector. Safeguards sensors have evolved from relatively simple analog devices and associated processing circuits to integrated solid-state devices with embedded sensors and intelligent digital signal processing.

Due to the IAEA safeguards mission requirement to provide an independent verification of member states' nuclear material declarations and activities, the sensor data security requirements are stringent and unique. All IAEA safeguards data must be complete, authentic, and unaltered, while sensor hardware, data storage, and data communications must all be secure. For example, in the area of containment, safeguards sensor security technologies have evolved from the application of simple passive mechanical seals on items of safeguards importance, to sophisticated electronic seals, tamper-indicating secure containers, and digital data authentication and encryption.

Facility, site, and state-level safeguard sensor systems were boosted by the revolution in computers, communications, and network technologies. The growth in electronic computing technology is legendary since its start as a room-sized computer based on vacuum tubes to micro-miniature solid state technology smaller than a coin—all during the same fifty-year period since the beginning of the IAEA. The original standalone devices were first hardwired together and later connected by computer networks. The communications media have evolved from copper to optical fiber to wireless radio frequency. Network management has changed from small dedicated networks to the global internet and virtual private networks (VPN).

In the following sections, we present illustrative examples of safeguards sensors, sensor security, and sensor systems from the past. Then we present examples that represent today's state of the art. Next, we venture into some examples of novel technologies that are in the early stages of research and development (R&D). Finally, we close with an epilogue regarding this international safeguards sensor applications arena that will be so vital to the present nuclear energy renaissance and the accompanying era of increased nuclear weapons proliferation concerns.

Examples from the Past

Surveillance Television and Recording System

In the mid-1970s, the IAEA began to develop the Surveillance Television and Recording System (STAR) as a direct replacement for the dual 8mm film camera system. Two versions of the system were developed concurrently—a hardware-based system and a software-based system using microprocessor technology. Ultimately, the IAEA selected the software-based system as the successor to the 8mm film camera system.

The STAR consisted of a tamper indicating enclosure that contained the following components:

- three Sony Betamax analog video recorders (a main, a backup, and a third recorder housed in a separate enclosure for use by Euratom, if required)
- multi-button user control panel
- video monitor
- power supply
- battery backup during main AC power outages
- An external tamper-indicating enclosure containing an analog video camera that connected to the system via a coaxial cable
- video circuitry that detected the loss of the camera signal and generated an internal video sync signal, which allowed for the recording of an annotated blank image during a camera failure condition.

All recorded video images were annotated with date/time, system state of health, and event/alarm codes. The recorders operated in a time-lapse fashion, in which a few images were recorded at a preprogrammed interval (5–20 minutes). This mode of operation allowed a one-hour videotape to last two to five months, depending on the interval, before the videotape was exhausted.

The STAR was ultimately replaced by the Modular Integrated Video System (MIVS).

The Modular Integrated Video System

The MIVS was the last analog system developed by Sandia National Laboratories for the IAEA, which used the system for surveillance purposes. The MIVS was a single-camera unit with two redundant videotape recorders that were housed in tamper-indicating enclosures. Although it was designed to operate with facility power, it had a limited backup power capability to cope with power interruptions. It also had a tamper-indicating system that monitored the video/power line from the main unit to the camera unit. The interval between scenes (snapshots) was adjustable; for example, if the interval was set at five minutes, the unit could record approximately 25,000 scenes over a three-month period, which was the typical time between IAEA inspector visits to a nuclear reactor facility.

Sandia developed the MIVS prototype system in the mid-1980s under DOE's program for international safeguards. System requirements evolved from interactions between Sandia and the IAEA's organization for system development. During the course of the development, Sandia contracted two commercial suppliers to produce and commercially manufacture units. Each manufacturer produced ten units, which Sandia then subjected to extensive testing. The tests involved temperature and humidity; "shake, rattle, and roll;" and reliability. The first two tests identified some problems that were corrected, while the last test determined the reliability of the MIVS to be 99+percent.

Under the U.S. Program for Technical Assistance to IAEA Safeguards (POTAS), the IAEA developed rigid requirements for the MIVS. Soon, a request to build the units was made public, and POTAS eventually selected Aquila Technologies Group in Albuquerque, New Mexico, as the MIVS commercial supplier. The MIVS became the workhorse for the IAEA surveillance efforts, but was ultimately replaced by units that were completely digital.

The Cobra Seal—A Passive Optical Fiber Loop Seal

In the early-1980s, Sandia National Laboratories initiated the development of a seal that incorporated a bundle of optical fibers. The concept was to capture the ends of a loop of a fiber optic cable into a seal body. This concept accomplished two things—it allowed for cutting a few of the randomly spaced sixty-four optic strands in the bundle, and it also secured the ends of the bundle in such a way that light could be injected in one end of the bundle while producing a unique light pattern at the other end. An adapter on the lens of a commercial Polaroid camera captured the unique pattern, which could then be used for future inspections of the seal. The seal body in the original design opened like jaws with cutting blades into which the loop would be placed. The closure of the jaws accomplished the cutting of the fibers. Because of the jaw's replication of a snake head, the seal received the moniker "Cobra Seal."[1]

This seal underwent extensive vulnerability testing, which proved to be successful.[2,3] The Cobra Seal has since been used in various applications by various organizations, such as the IAEA, European Commission, and U.S. embassies.

Sandia requested proposals to produce the seal commercially, and Aquila Technologies Group of Albuquerque, New Mexico, was awarded the contract.

Active Optical Fiber Loop Seal Technology

The IAEA is currently using a radio frequency communication fiber optical seal known as the T1 at the Savannah River K-Area Material Storage (KAMS) facility. These seals are used to monitor containers of plutonium oxide that the U.S. nuclear weapons program declared as excess to defense needs. Using the capability developed by Sandia National Laboratories, the IAEA was able to conduct pioneering work by providing a remote facility verification capability for inspectors in Vienna using these seals and the attendant authenticated data gathering system.

These seals have a unique history. The concept began in the early-1980s, when Sandia was challenged by the U.S. Department of Energy (DOE) to develop a system to protect the N-reactor at the Hanford Site from sabotage and insider threats. A system analysis to prevent the successful potential sabotage sequences identified the need for sealing certain valves and other system components. For this domestic security application, Sandia developed the Wireless Alarm Transmission of Component Health (WATCH), which was a fiber optic loop seal that provided the status of valves (opened or closed) and the status of other components in the reactor safety system through radio frequency communication. This system proved to be a vital element of the N-reactor's security system.

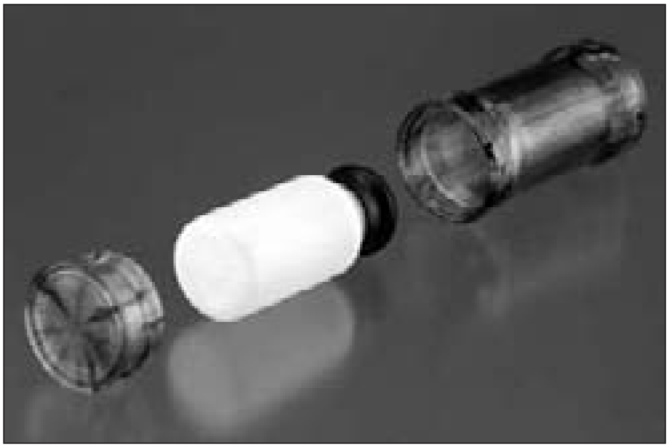
With the successful implementation of the WATCH system at N-Reactor, the WATCH capability was extended for potential use by the IAEA. This decision required the system to be placed in a more secure tamper-indicating enclosure and the optical loop to be monitored for tampering in a more secure manner. This new system, developed in the mid-1980s under the sponsorship of the DOE, was named the Authenticated Item Monitoring System (AIMS).

At the request of a non-DOE sponsor, the AIMS technology was further developed to track cargo on trans-oceanic vessels. This extended system, known as the Authenticated Tracking and Monitoring System (ATMS), successfully tracked cargo from Australia to Europe in the late-1980s.

In the early 1990s, Sandia's weapons program decided to develop a monitoring system for the Pantex Plant storage bunkers. This new system, known as "Straight Line," proved successful in several working environments, and evolved into the T1 seal. The T1 program had major objectives, including improving power management to achieve longer battery life, developing a robust capability to monitor the optical loop for tampering, extending the allowable length of the loop, and developing strong communication links between the seal's transmission antenna and the data-collection and display receiving units.

In the mid to late 1990s, the T1 system was chosen to monitor plutonium stored at the KAMS facility at the Savannah River Site. Originally, the system was considered only for domestic safeguards applications, with the intent of reducing the frequency of verifying container contents. Subsequently, however, material at Rocky Flats, including some material under IAEA safeguards, were transferred to the KAMS facility, and the T1 system was modified to be used by the operator for domestic safeguards and by the IAEA for international safeguards. However, before the IAEA accepted the T1 for routine use at KAMS, the system underwent extensive testing, with the intent to identify vulnerabilities. After two years of IAEA evaluation, including using the system in demonstrations at KAMS, the IAEA accepted the system for routine use.

Figure 1. SVSC components



Sample Vial Secure Container

Sandia National Laboratories developed the Sample Vial Secure Container (SVSC) system to meet a specific IAEA requirement involving the Tokai Reprocessing Plant in Tokai, Japan.[4] In the presence of an IAEA inspector at the plant's blister sample station, samples are drawn from plutonium product and spent fuel input tanks. These samples are then placed in unsecured cartridges and transferred to an analytical laboratory using a pneumatic system. The IAEA understandably had concerns regarding the security of the samples during transfers, and the SVSC system was subsequently designed to address this concern.

The SVSC is a passive tamper-indicating pneumatic tube rabbit that consists of three components: a cartridge, cover, and identification labels with randomly generated codes (see Figure 1). The identification labels are placed inside both the cartridge and the cover, and the sample vial is inserted in the cover. The cover is then pressed into the cartridge, causing the two halves to interlock. After this, the only way to reveal the codes is to cut open the SVSC with a specific cutting device. Safety features have been incorporated into the cartridge and the cutting device to assure operation will not result in the release of sample material from the vial.

Although the SVSC was successfully demonstrated at the IAEA, it was never used for its intended purpose; instead, the IAEA has used the system to store samples as needed.

Today's State of the Art

Seals—Current State of the Art

Today, the seals most often used for international safeguards are passive seal designs that have been around for over two decades—the e-cup metal seal and the Cobra Seal. Although the designs and verification procedures for these seals have been modified over the years to address potential weaknesses and to allow new manufacturing processes to be used, the basic seal designs remain the same.

The situation in active seals is much more dynamic. New processors and other components are continually being developed and older components are phased out of production as they become obsolete. As a result, new seals must constantly be developed not only to continue incorporating new capabilities that become available with new technological advances, but also to avoid a situation in which replacement seals cannot be produced when critical components can no longer be obtained.

The VACOSS fiber optic electronic seal, developed for the IAEA under the German Support Program, has seen widespread use since its introduction in the late-1980s. Its successor, the Electro-Optical Sealing System, also developed under the German Support Program, is in the final stages of approval for deployment for safeguards use. This new seal has enhanced cryptographic capabilities and improved tamper detection technology, along with other design enhancements.

The T1 seal, discussed earlier in this article, is no longer in production. Its replacement, the T1A seal, has not yet been accepted for use by the IAEA. The Secure Sensor Platform, which is being developed primarily as a sensor host and interface platform, also functions as a fiber optic seal and will probably replace the T1A.

Distributed Data Collection Systems for Large Facilities

As the facilities under safeguards become larger and more complex, distributed data collection systems must be used to monitor activities in the facility and to bring the resulting data to a central data repository for the inspectors. This allows the inspectors to use their time on the site reviewing data, rather than visiting the various monitoring systems to collect data storage media, as would be the case if several autonomous data collection systems were used at the facility.

Unfortunately, the data security issues with connecting these computers in a network are not trivial. In order to ensure that the data are authentic, the system must be protected from possible attacks everywhere in the network. It is not practical to consider physically protecting non-IAEA network cables and computers from tampering, and the virtual private network (VPN) technology that is used for transferring the data over public networks is sometimes unsuitable for the network architectures inside operational facilities.

The data collection system for the Rokkasho Reprocessing Plant is an example of the data security problems encountered in a large facility, yet also serves as an example of a workable solution to these problems. This large facility has activities in several buildings that are monitored. The IAEA's approach to monitoring these activities was to install one or more "local cabinets" (LC) in each of the buildings. Each LC contains one or more computers that collect surveillance or nuclear measurements data. The LCs are connected to an "inspectorates' cabinet" (IC), which is located in each building and is shared by the IAEA and the Japanese Safeguards Office (JSGO). The JSGO, along with the Nuclear Material Control Center (NMCC), supplies and maintains the ICs. Data are buffered at the IC before being forwarded to the Raw Data Base (RDB), which is also supplied and maintained by the Japanese. The IAEA then downloads the safeguards data from the RDB to its own computers in the IAEA inspectors' office for storage, review, and analysis.

Each LC is housed in a tamper-indicating cabinet that is sealed with an IAEA seal. Since not all of the network cables and computers are under the IAEA's control, the LCs must be protected from the threat of attack over the network. The data must also be protected from alteration or other modifications while in transit through the network to the IAEA computers.

A Netscreen VPN appliance inside each LC addresses network attacks. Because the system architecture does not allow active connections between the computers inside the LC and the IAEA computers, the security function of an encrypted VPN is not used. Instead, the devices are used as hardware firewalls and are configured to allow only very limited network traffic into or out of the cabinet. Currently, the only network traffic allowed into the cabinets is the network time protocol (NTP), which allows all the computers to be synchronized to a central time source. Outbound traffic is limited to file transfers using file transfer protocol, and only the local computer is able to initiate each transfer.

All data are cryptographically authenticated before being sent out of the LC. Surveillance data from the cameras are authenticated by the DCM-14 camera modules, so no further authentication is required. All other data are digitally signed using the Sign and Forward system, described later in this article. The cryptographic tokens used in the Sign and Forward system have an internal clock that is used to verify that the time signals received from the NTP server have not been falsified.

Data Authentication

It is essential that the data used to draw safeguards conclusions are authentic. It must be known that the data originated from the intended source, that the data were not changed in transit, and that it is not a repeat or delayed copy of previous data. One approach to ensuring this authenticity is to maintain a secure physical boundary around the equipment recording the data and then to physically secure the data media until it can be loaded onto trusted equipment for review and evaluation. In other words, the equipment is sealed inside a tamper-indicating enclosure until the inspector takes the data to IAEA headquarters for review. As the number and complexity of sites being monitored increases, this approach becomes unwieldy, due to the labor costs involved and the difficulty in maintaining physical security on large amounts of data that an inspector has collected from multiple pieces of equipment. An alternative approach is to use cryptography to put a digital authentication code or digital signature on the data. After cryptographic data authentication has been applied, the security requirements for transporting the data to the review location are much less stringent.

In the early 1970s, Gus Simmons and Paul Stokes worked on authentication for remote seismic monitoring systems. This was probably the first time that cryptography had been applied to the problem of data authentication. Although their algorithm was not fielded in the Deployable Seismic Verification System, the concept of authentication eventually used was the same.

From the beginning, however, the key management problems associated with this approach to data authentication were troublesome. These early systems were based on symmetric key cryptography, which requires that the same key be used for both signing and verifying the authentication. In a bilateral or multilateral situation, anyone who could verify the authentication could also generate false data that appeared to be authentic. There were also problems associated with maintaining the security on a large number of secret authentication keys as they were loaded into the equipment and as they were used by the inspectors in the field.

The development of public key cryptography in the late 1970s offered a solution to this key management problem. With this cryptography, different keys are used for signing and verifying the authentication. The private (secret) key only exists in the monitoring device, while anyone wishing to verify the authenticity of the data could have a copy of the public key without compromising the security of the private key. Unfortunately, the calculations involved are very complex and these public key algorithms could not be deployed in the camera and seals systems of the day because the microprocessors required to perform these calculations would quickly drain the batteries.

Recent developments in microprocessors and cryptography are now allowing systems to be developed that will include public key signature technology. The Next Generation Surveillance System currently under development by Canberra Albuquerque and Dr. Neumann Consultants will employ public key cryptography. The new Secure Sensor Platform under development by Sandia National Laboratories and Canberra Albuquerque will also use public key technology in a very low-power device.

The IAEA developed the Sign and Forward data authentication system to have a standardized approach to authentication for its unattended and remote monitoring systems that do not have other authentication measures built into the sensor platform. In this system, an extra layer of physical security is added by using dedicated cryptographic hardware tokens to store the keys and to perform all the cryptographic calculations. This system is currently being deployed worldwide.

Virtual Private Networks

VPN technology was developed to allow secure communications over public networks. This was very attractive to the safeguards community due to the high cost and questionable security of leased lines, satellite, and other approaches to collect data from remote monitoring sites.

Sandia first implemented a VPN to transfer safeguards data internationally from Finland to Vienna in 1999. Since then, the IAEA has deployed VPN technology in Korea, Japan, and several other locations worldwide.

The VPN technology was chosen to be deployed in dedicated hardware devices rather than using software on the data collection/data server computers. Using these certified and tested modules simplifies installation and improves security while reducing the probability that the VPN configuration will be maliciously or accidentally modified by users or by other software on the computer.

Tamper-Indicating Enclosures

Tamper indicating enclosures (TIE) are used to provide assurance that unattended and remote monitoring equipment has not been tampered with during the time inspectors are not directly observing the equipment. Two approaches are used to provide this assurance—active and passive. Active technologies use continuously powered sensors that can provide instant indication of tampering attempts. Passive technologies require onsite inspection by trusted personnel. Passive technologies are most frequently used because of lower costs and a higher level of assurance that any attack attempt will be detected. Unfortunately, passive technologies do not provide information about when the attack took place, only that it occurred between inspections. As the period between inspections increases, there is mounting concern that the inspecting agency's timeliness criterion for detection of material diversion might not be met.

The approach most often used in passive tamper indication employs enclosure surfaces, which are difficult to repair when an attacker attempts to conceal tamper attempts. Aluminum that has been anodized in a light color has proven to be very effective, as are some special coatings. Detection of penetrations is much more likely if the inspector has access to the inside of the enclosure, since it is much more difficult to repair damage when the attacker's access is limited by the enclosure's design. The use of eddy current or ultrasonic equipment that can detect changes in the material composition and structure can provide higher assurance of the enclosure integrity. This equipment continues to become more and more inexpensive, making these inspection techniques affordable.

Many active tamper detection technologies have been investigated, including resistive, capacitive, and piezoelectric membranes inside the enclosure. In the past, these have been too expensive and have consumed too much energy for routine use. Technology advances, however, have resulted in renewed interest in these technologies. The processor used in the Trusted Radiation Attribute Detection and the Trusted Radiation Identification Systems employs a special printed circuit board that will detect attempts to drill into the ends of the enclosure, while the Electro-Optical Sealing System uses a flexible foil for the same purpose.

Many different approaches for using fiber optics have also been investigated. This includes wrapping the enclosure in optical fibers or fabricating panels with optical fibers laid closely together. A pulse of light would then be passed through the fiber to monitor integrity. Any attempt to penetrate the enclosure would result in breaking one or more fibers, causing a loss of the transmitted light pulse. Although using optical fibers for this purpose might be attractive, they are currently too expensive; for that reason, the only use for optical fibers is in the loop seals discussed earlier.

Remote Monitoring

The International Remote Monitoring Project (IRMP) was initiated in the early 1990s to improve the efficiency and effectiveness of international safeguards. A remote monitoring system uses versatile network technology to integrate video surveillance with a variety of specialized sensors that detect motion, radiation, temperature, tampering, and other information or events.

The objective of the IRMP was to support the IAEA goal of using remote monitoring in specific facilities under safeguards. The purpose of remote monitoring is to maintain Continuity of knowledge of nuclear materials during the absence of IAEA inspectors. Therefore, remote monitoring systems are required to work reliably and robustly in a host nation facility for months at a time, should be resistant to tampering capabilities that could be mounted with national level resources, and should be able to withstand uncertain electrical power supplies without the loss of significant safeguards data.

When compared with conventional measures, remote monitoring offers the following advantages for nuclear material safeguards:

- Enhanced international safeguards effectiveness
- Reduced inspection costs to the IAEA
- Reduced radiation exposure to inspectors
- Reduced intrusiveness to facility operators

An intensive effort on the part of many member states and the IAEA was successful in identifying system hardware and software components that would meet the stringent reliability and robustness qualifications stated above. However, excessive data transmission costs still made remote monitoring unattractive as a safeguards tool, until the remote monitoring systems were coupled with data security tools that allowed the use of the internet, such as VPN. This breakthrough in transmitting large volumes of safeguards data securely and with very low costs allows the IAEA to now receive the full benefit of the effectiveness and efficiency promises that have long been a goal of remote monitoring.

3D Mapping

A current technology development activity of interest is 3D sensing technologies in safeguards applications involving monitoring and inspection systems. Of particular interest is the application of 3D mapping technologies to improve surveillance and confirm design information to detect a change in configuration of a safeguarded nuclear facility. In this project, the Joint Research Center (JRC) at Ispra, Italy, Sandia National Laboratories, and Oak Ridge National Laboratory (ORNL) are evaluating the uses, limitations, and effectiveness of various approaches to 3D monitoring and inspection. Specifically, JRC developed a laser-based 3D mapping system that has been tested both in indoor and outdoor applications, while Sandia developed a multi-camera system for volumetric motion detection. These approaches are complementary, with various strong points for certain applications. The evaluation will provide critical guidance on the deployment and application of these 3D technologies to both TREN's Euratom Safeguards and the IAEA inspectorates, and complements the work already conducted by ORNL to evaluate the efficacy of using the JRC technology for the verification of plant design in safeguards applications.

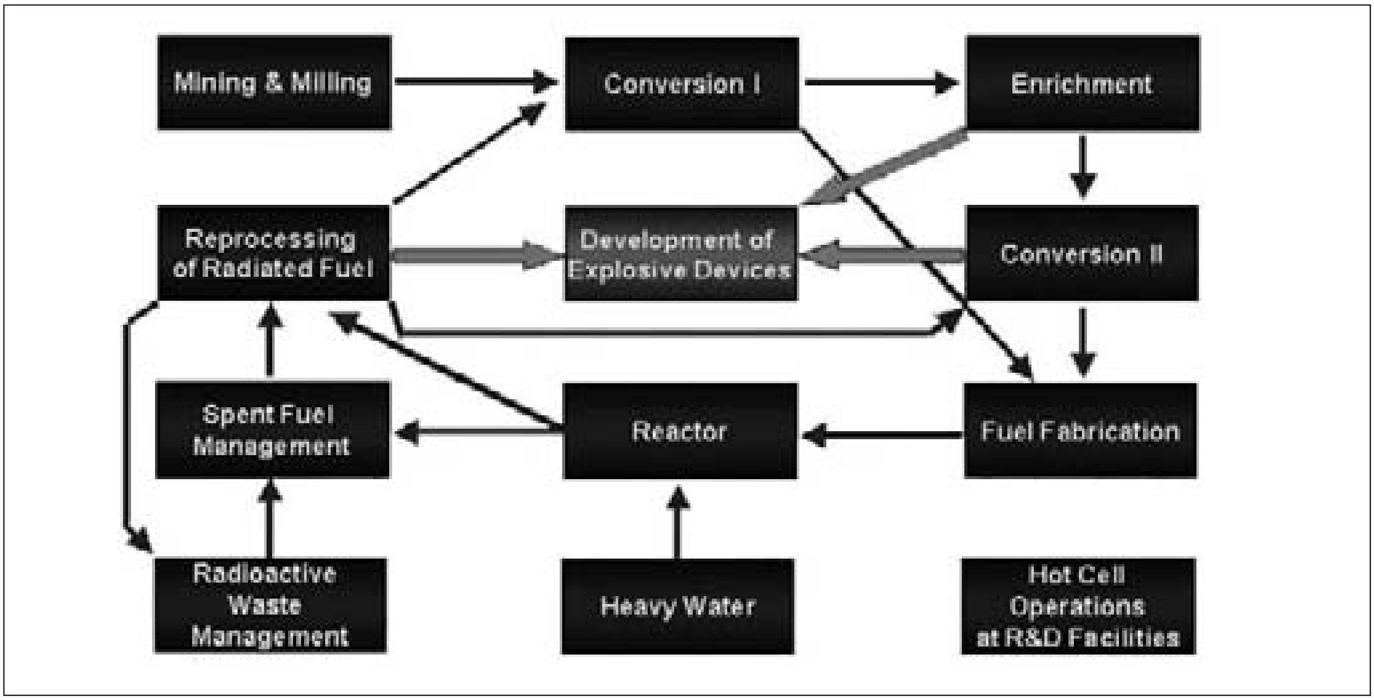
There are several technical issues critical to the application and deployment of 3D sensor technologies. For example, portions of monitored areas can remain relatively static while other portions, including those occupied by humans or machines, can be very dynamic. Relatively static components require mapping every few minutes; dynamic components require 3D mapping at much higher rates. Furthermore, to function in exterior environments, the sensing system needs to maintain an adequate level of insensitivity to natural changes in lighting and other environmental factors including temperature and humidity. For applications requiring stealth, active sensing modes need to be carefully controlled. Application in potentially hazardous environments requires rapid, easy installation and calibration of sensor systems. Material tracking using 3D imaging systems requires automatic object detection and recognition. Also, the capability of interfacing with surveillance and/or remote monitoring and verification systems, some of which have already been fielded, also needs to be evaluated.

Both Sandia and JRC have used and/or developed different 3D sensing technologies suitable for monitoring and inspection applications. In the meantime, new 3D technologies are becoming commercially available. All of these systems differ in several regards including cost, application base, and sensor modalities. These 3D systems have the potential to provide significant advantages for monitoring initiatives.

Novel Technologies for Tomorrow

The early detection of an undeclared nuclear facility, activity, or material will require advanced approaches, supplemented by technologies that may differ significantly from those used traditionally for onsite verification. The IAEA Medium Term Strategy for 2006 to 2011[6] includes the enhancement of its detection capabilities through the development of new or improved safeguards approaches and techniques, and the acquisition of more effective verification equipment. Within this framework, the IAEA established the project *Novel Techniques and Instruments for Detection of Undeclared Nuclear Facilities, Materials and Activities* to identify specific implementation needs that may not be met by traditionally used methods and instruments, and to initiate any necessary R&D of novel techniques and instruments that could provide more effective solutions for the IAEA's implementation of additional protocols, including the conduct of complementary access.[7]

Figure 2. A simplified schematic of the nuclear fuel cycle



Development and Implementation of Novel Safeguards Methods and Instruments

Implementation of effective and efficient safeguards has relied increasingly on the development and deployment of methods and instruments meeting specific functional and technical requirements. As outlined above, equipment development has complemented the IAEA's safeguards implementation approaches over the past decades. For example, early safeguards equipment was developed for the main purpose of supporting onsite materials and activity verification at declared locations.

After the 1991 Gulf War and the discovery of a clandestine nuclear weapons program in Iraq, safeguards approaches were enhanced to include additional methods and techniques, providing the IAEA with further tools by which it could better detect undeclared activities. These included environmental sampling, information analysis, sensitive technology monitoring, and satellite imagery. New technologies, such as ground penetrating radar, were also developed in support of conducting complementary access.

By their very nature, clandestine nuclear processes are undertaken at undeclared locations, or at declared locations that may be used as a *cover* for an undeclared process. The discovery of such activities requires appropriate equipment that can detect unique characteristics related to the particular process. The Novel Technologies Project aims to broaden the range of techniques and instruments available to the IAEA, including emerging novel techniques and instruments that can assist in the detection of undeclared activities in undeclared locations (e.g., small industrial areas, universities, workshops, etc.).

Figure 2 shows a simplified nuclear fuel cycle (NFC) comprising the processes, in general form, which can lead to either material for nuclear power generation or for weaponry.

Through a systematic and detailed analysis of each NFC process, it is possible to determine the existence of unique *indicators* and *signatures*[8] that would be strong signs of clandestine operations.

The Novel Technologies Project is reviewing indicators and compiling signatures for all critical NFC activities; identifying those with the most promise for detection, particularly at a distance; and performing gap analyses to identify suitable methodologies, or instruments, for safeguards applications. Where a suitable methodology or instrument does not exist, then the project, with the support of member states, will pursue the required development and testing that will result in a safeguards-appropriate solution.

Novel Technology Development and Evaluation

Several technologies have been selected by the IAEA for further development and evaluation to meet specific needs for either onsite or off-site detection of undeclared activities.

Nuclear Forensics

Optically stimulated luminescence (OSL)—A location may be suspected of having been previously used for the storage of, or activities involving, radioactive materials. During complementary access, an IAEA inspector encounters the same location disguised to appear as an ordinary functioning office. To verify the previous purpose and use of the location, the inspector collects samples of the surrounding building materials and transports them to an analytic laboratory for OSL analysis. The collected samples are analyzed for residual nuclear activation by OSL, indicating the previous presence of stored nuclear materials.

Laser-induced breakdown spectroscopy (LIBS)—Unidentified materials may be found during an onsite visit. A trained IAEA inspector operates the LIBS unit to produce a spectroscopic profile, which is then compared to those in the LIBS system's library to determine the material's makeup. LIBS typically comprises a laser system to ablate the surface of the material to be analyzed to create a micro-vapor, and a spectrometer to generate a spectroscopic profile of the micro-vapor constituent components. The resolution of the LIBS is mostly dependent on the design of the spectrograph. It has been suggested that such instruments could be designed to provide both elemental and isotopic results.

Atmospheric Sampling

Light detection and ranging (LIDAR)—LIDAR techniques are used routinely by environmental monitoring agencies to determine the presence of pollutants in the atmosphere. For example, a LIDAR-equipped vehicle may travel to the vicinity of the suspected location engaging in an undeclared nuclear fuel cycle process. A laser, tunable to precise wavelengths (λ), selectively stimulates specific airborne molecules emanating as a gaseous compound from the process. A light-sensitive telescopic spectroscope scans the atmosphere to detect the presence of the stimulated molecules.

Sampling and analysis of atmospheric gases—A mobile gas-sampling vehicle travels around the region of interest collecting and concentrating atmospheric-borne pollutants. Local meteorological conditions and the GPS location are also recorded at each sampling location. The collected samples are transported to a laboratory for analysis. The field-collected sample data are combined with meteorological data and suitable atmospheric backtracking simulator to provide an estimate of the source direction. The airborne material is identified and the probable location of the source is estimated.

In parallel with the tasks outlined above, the project has also convened specialist technical meetings on techniques for the verification of enrichment activities, noble gas sampling and analysis, and laser spectrometry techniques. Further specialist meetings covering novel technologies are being planned. Additionally, the project has been active with the support of member states in establishing contacts with international R&D organizations and experts engaged in a wide range of sensor and detection technologies. Thirteen member state Support Programmes (MSSP) have also agreed to assist the project by facilitating technical exchanges with both private and government-operated R&D laboratories and by providing access to experts for short-duration tasks, attending technical meetings, advising on novel methods and instruments, conducting field tests, and providing supplementary funding.

Additional technologies have been proposed as supplements to, or alternative solutions for, current and emerging Safeguards verification activities, complementary access (CA), forensic, and other standoff detection needs. Illustrative examples of proposed technical solutions supporting the traditional areas of non-destructive analysis (NDA), containment and surveillance (C/S), and other onsite and off-site inspection activities include the following:

Verification of the Operation of a Gas Centrifuge Cascade

- Need: To detect the presence (or to verify the absence) of enrichment above declared levels in a declared gaseous centrifuge plant producing low enriched uranium (e.g., countering undeclared production or embedded micro-cascade scenarios)
- Proposed Solution: Install a low-power, self-organizing network of neutron detectors above the centrifuge cascade. Data from each neutron sensor is collected and processed to produce a continuous indication of the relative enrichment levels throughout the cascade.

UF_6 Enrichment and Material Flow Monitoring

- Need: Non-intrusive enrichment and flow monitoring for a gas centrifuge facility
- Proposed Solution: Measure both enrichment and material flow rate, without penetrating cascade pipe-work, using nuclear magnetic resonance with a relatively low magnetic field. Placement of two or more sensors on the pipe will allow both enrichment and flow-rate measurements.

Verification of the Operation of a Gas Centrifuge Cascade

- Need: Uranium enrichment sensor for GCEP over time (countering the "microcascade" scenario)
- Proposed Solution: Install many simple, robust, low-cost OSL sensors at strategic points within the cascade and pipe-work. Exposure to radiation from within the cascade components (e.g., pipe-work) will cause the OSL-sensitive material in the tab to be stimulated. The relative level of stimulation will be proportional to the time-integrated radiation intensity. The relative exposure of each tab to the incident radiation is measured.

Onsite Analysis of NFC Process Trace Materials

- Need: More rapid, onsite material analysis for the pre-screening and detection of undeclared enrichment or reprocessing activities
- Proposed Solution: Use Laser Ablation/Laser Induced Fluorescence (LALIF). While current LALIF is capable of detecting 10μm (or nanogram mass) particles, the technique is orders of magnitude less sensitive than laboratory analysis of environmental samples. However, it does provide other benefits, including rapid onsite analysis of relatively large material deposits (including the detection of ^{236}U) and the identification of metals and alloys.

Verification of the Operation of Research and Power Reactors

- Need: To monitor the core operating conditions of a nuclear reactor (research and power types)
- Proposed Solution: Install an antineutrino detector in a convenient location within, or near, the reactor building. The operation of the reactor core and its relative power level can be monitored directly over time.

Detection of Specific NFC Chemical Compounds

- Need: To detect specific chemical compounds associated with NFC processes
- Proposed Solution: Utilizing a micro-machined pre-concentrator with a hybrid of a gas chromatography channel and a quartz surface acoustic wave array (SAW) detector, the system is capable of sensitive/selective detection of gas-phase chemical analytes. It can be "pre-tuned" to targets of interest, during fabrication, by careful selection of absorption film layer. Developed by Sandia National Laboratories, it is now a commercial product, marketed under the name µchemlab. The technique could be used to detect the presence of specific NFC chemical compounds.

Stand-off Detection and Analysis

- Need: To detect specific radiant energy from nuclear processes
- Proposed Solution: A source of activity is capable of producing information, matter, and radiant energy, which may be detectable with an appropriate method or instrument. By further investigating other portions of the electromagnetic spectrum, it may be possible to detect and identify the location of an undeclared nuclear activity. These techniques include satellite, airborne and land-based spectroscopy, infrared and panchromatic spectrometry, and the detection of acoustic and other electromagnetic emanations.

Novel Technologies Prospectus

The establishment of the Novel Technologies Project has provided a mechanism for the IAEA to address the technologies required for emerging and future inspectorate needs. Moreover, it has facilitated the IAEA's access to a greatly expanded range of methods and instruments, thereby allowing safeguards planners the opportunity to develop novel verification and detection approaches for the peaceful use of nuclear energy and applications.

The project will continue to conduct surveys to identify safeguard needs that cannot be met with available techniques, broaden technical collaboration with other nonproliferation organizations and the international R&D sector, and, where required, initiate further tasks that will lead to safeguards-useable methods and instruments. The basis of that will be a review and analysis of the nuclear fuel cycle processes, identifying the most safeguards-useful activity indicators and emanating signatures that can "travel" from the source location and can be detected with a high level of confidence and accuracy. Indicators and signatures will be information, matter, and/or energy associated with a particular nuclear fuel cycle process. Once identified, methods useful for the detection of promising indicators and signatures will be assessed by experts to determine if suitable methodology or instruments are available. Where none exist in a safeguards-useable form, the project will define appropriate technical and procedural requirements, initiating the necessary R&D and testing regimes.

Technology Trend Enablers

Much of today's state-of-the-art technology was not envisioned in 1957, and we cannot expect to accurately predict much of the technology that will be used in the safeguards systems of 2057. However, we can recognize some of the technology trends that will be driving the sensor systems for the near-and mid-term safeguards applications.

The first factor is the potentially revolutionary basic research that is being conducted in materials science. There is an expectation that in the future scientists and engineers will be able to design materials with unique customized properties and behavior. This work will most likely be accomplished at the atomic scale of matter. When this research is successful, then application-specific integrated sensors would become possible. We can envision higher sensitivity, higher selectivity, lower power, longer range, and more.

A second factor will be the almost expected continuing innovation in computing technology and systems. In the long term, materials may be the key to biological cell basic computing units and their integration into assemblies of organic computers with embedded algorithms and processing that rivals or surpasses the human brain. In the near and mid-term, there are expectations for continuing advancements in reduced scale, larger memory, higher speeds, and lower power.

A third factor will likely be new developments in networking and communications that will be driven to a large extent by the continuing computer revolution and to a lesser extent by the materials revolution. Wireless technologies will dominate. Pervasive coverage and penetration will be achieved. Autonomously configured continually dynamic networked communications will become the norm.

This will all be good news for secure safeguards sensor systems applications. While IAEA safeguards will not drive the revolution, it will surely benefit from the greatly enhanced technology effectiveness and performance, and the affordability, quality, and reliability driven by the increased global market demand.

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7. "New technologies" are defined by the project as those for which the methodology is already understood and implemented by the agency for safeguards applications. Examples include the next generation surveillance and sealing systems. "Novel technologies" are defined by the project as those for which methodology has not been applied previously to safeguards applications. Examples include laser spectrometry and spectroscopy.
8. "Indicators" are entities that go into making the process operative. Examples include information and/or materials in the form of necessary resources, facility design data and related R&D. "Signatures" are entities produced by the process when it is in operation. Examples include information, materials and/or radiant energy in the form of operational reports, produced materials, process byproducts and energy emanations.

Safeguards Instrumentation—A Look Back

Marius Stein, Steve Kadner, and Michael Goldfarb
CANBERRA Albuquerque, Inc.
Albuquerque, New Mexico, USA

Introduction

Congratulations to the International Atomic Energy Agency (IAEA) on reaching its fiftieth anniversary: fifty years of leading and guiding the international safeguards and nonproliferation community toward a nuclear weapons-free world where everyone can benefit from peaceful nuclear energy. Hard and steady work throughout five decades, not only by the IAEA itself but also by the Nonproliferation Treaty (NPT) member states, in the face of global tensions, wars, and the constant threat of proliferation of nuclear weapons, materials, and technologies is truly a remarkable feat.

While each IAEA mission pillar is crucial to the success of the Atoms for Peace vision upon which the agency is founded, it is the Department of Safeguards and its task of verifying declarations of NPT signatory states that faces the full impact of geopolitical crises, covert nuclear programs, and international tensions. The challenges during these first fifty years have truly been manifold. They still exist today, as IAEA inspectors travel to nuclear installations worldwide to conduct safeguards inspections and gather information required to draw safeguards conclusions. The constantly changing global environment and policy developments that follow in the wake of every major political event affecting the use of nuclear energy continue to impact the work of inspectors, the scope of the inspection regime, and the use of instrumentation that is installed in and carried to facilities to enhance inspector' senses.

In the broadest sense, safeguards instrumentation has been used since the early 1960s. When safeguards inspections were first begun, samples of nuclear materials taken from facilities were analyzed to match the actual material composition against an inspected state's declarations. After the NPT went into force in 1970 and more nuclear installations became part of the safeguards regime, the growing need for analysis capabilities prompted the construction of a dedicated Safeguards Analytical Laboratory (SAL). Opened in 1975, the SAL was accompanied by the implementation of the Network of Analytical Laboratories (NWAL) to further extend analysis capacities. Even so, hand-carried and installed instrumentation have been used from the very beginning of declaration verification efforts. The first seals (borrowed from U.S. taxation authorities) and non-destructive assay (NDA) instrumentation for in-field measurements were used as early as 1966.

The mechanisms and procedures the IAEA uses to find the appropriate instrumentation to support its inspectors in the field have evolved significantly over the past half century. These methods give an interesting insight into how the agency operated throughout the decades. The following paper will shed some light on the origin of safeguards instrumentation, how it was developed, procured, and placed into the able hands of inspectors for use. Rather than giving a comprehensive overview on all instrumentation ever used by the IAEA (others have done a great job at that already), it will outline some of the agencies, partners, and individuals involved in developing and manufacturing instrumentation, and in providing new solutions and applying new technologies in support of the IAEA. Some of the great technology surprises that fundamentally changed safeguards dogmas throughout the years are highlighted along with the key players that drove these changes. A look into the future on how instrumentation will evolve in the decades to come will conclude the paper.

The Early Days—Beg and Borrow

The fundamental basis of all safeguards efforts is the verification of safeguards relevant declarations of an NPT member state (e.g., the verification of declared nuclear materials accountancy statements or verification of facility design). The verification of declared accountancy statements is based on the premise of detecting diversion of nuclear materials in a timely fashion, thereby providing a deterrence barrier for possible adversaries (correctness of declarations). To assure the absence of undeclared nuclear programs, inspection efforts have to be exercised to detect parallel undeclared nuclear activities (completeness of declarations).

To support verification of declaration efforts, IAEA inspectors have made use of instrumentation from the very beginning. However, because safeguards inspection was a new, unfamiliar concept with unique requirements, the appropriate tools were not easily available and had to be carefully identified from other, similar applications. NDA was an area where instrumentation developed for domestic or multinational (Euratom) purposes (e.g., national accountancy, personnel safety, and quality control) could in principle be applied to verification efforts. However, certain critical features (e.g., portability, ruggedness) and the need for standardization had to be kept in mind. The use of NDA instrumentation was not trivial and called for IAEA inspectors to be well trained and familiar with nuclear physics.

There were other areas from which early instrumentation was borrowed. The aforementioned U.S. Internal Revenue

Service (IRS) seal was later developed into the Type-E metal seal, which is still in use today, and the first adhesive paper seals are two examples for passive seals used by IAEA inspectors. A few years later in the early 1970s, advances in the market for commercial and industrial filming products made another sensor adaptable and available for safeguards use: surveillance cameras. Ranging from 8-mm to 35-mm and customized for IAEA use to various degrees, surveillance systems became the first instrumentation fixedly installed in nuclear facilities to record event data (e.g., open core operations, hatches, etc.) while the inspectors were not present themselves.

While film added new depth to the information contained in safeguards conclusions, it also obliged inspectors to undertake unfamiliar measures: Inspectors had to be trained to operate a new set of instrumentation. Because the instrumentation was not developed specifically for IAEA use in most cases, use of film forced inspectors to some unconventional measures such as developing film in hotel bathroom sinks and bathtubs. The first surveillance system used in broad application was the Twin (and sometimes Triple) Minolta XL-401, introduced for IAEA use in 1978. This surveillance system allowed for battery operation, could be set to a fixed or random picture taking interval (PTI), and made use of two or three parallel channels for increased reliability or reduced PTI.

Early safeguards instrumentation was provided to the IAEA mainly through donations by member states. Safeguards-specific modifications were conducted as direct cooperation between the IAEA and research and development institutions in various countries or multinational communities. R&D institutions that cooperate with the IAEA include Los Alamos National Laboratory (LANL) and Sandia National Laboratories (SNL) in the United States, KFZ Jülich in Germany, and JRC Karlsruhe for Euratom, each supported by the funding of the respective member states. With the growing demands for safeguards in the late 1970s, multiple member states decided to establish dedicated support programs (MSSPs) that have been crucial to the success of safeguards implementation to this day. These provide the IAEA with extra-budgetary assistance for coordinated instrumentation research and development, systems studies, specialized expertise, training, and other important services.

Portable to Unattended—A New Dimension

The application of instrumentation was impacted in the mid-1980s by the introduction of large-scale, high-throughput facilities. These facilities employed automated processes and materials that could no longer be easily extracted from the process flow for verification measurements. The concept of unattended NDA measurement instrumentation that resided at a facility and continuously gathered data was introduced and the first systems developed by LANL. Together with the shift from film to video a few years later, this caused a significant reduction in the need for physical inspector presence at a safeguarded facility. It also raised questions of data security, authentication, and review.

This era also saw a flood of various instruments entering the IAEA as research and development laboratories, educational institutions, and other agencies supported by their respective MSSPs tried to establish their inventions as safeguards standards. Most notably, the establishment of extra budgetary support by the United States specifically for the acquisition of safeguards equipment marked a major turning point in the availability of funds for safeguards equipment implementation. While this made available a broad range of expertise and solutions to IAEA inspectors, it also increased the number of systems that the inspectors had to be trained to use and that had to be serviced and maintained. At the same time, since the number of systems needed for each specific instrumentation discipline had reached hundreds rather than dozens from the decades before, commercial companies began investigating if safeguards would present a sustainable market worthy of attention.

Developed by SNL in 1989 and later produced by a private company, Aquila Technologies Group (ATG), the Modular Integrated Video System (MIVS) was the first video system to be broadly applied by the IAEA in the field. MIVS marked the first time a large supplier contract was issued in an open tender, and it was the first time a private company cooperated with an R&D institution to commercialize safeguards instrumentation on a large scale. In fact, it was such an unusual occurrence for a private company to deal with the IAEA as an entity that the U.S. Import & Export Bank agreed to issue a guarantee to ATG to cover the risk of dealing with this unknown, foreign customer.

While the digital surveillance system development was underway, the IAEA had to continue to maintain the 500 surveillance cameras in operation, deal with the technologically forced decommissioning of its film camera inventory, and keep up with the burgeoning demand for additional surveillance installations that demanded a doubling of the number of surveillance applications. In parallel the IAEA had to meet the strategic need for faster and faster PTIs, and a level of reliability far exceeding commercial applications. During this period, the analog multi-camera system MXTV operated about 200 cameras, and the MIVS system a similar amount before confidence in the digital systems was sufficient to start a gradual evolution to the modern technologies.

With video came the need for review tools to remove the need for the analysis of every single image that was taken during the inspector absence. A broad number of applications were developed, including MIPS (SNL), Mark 2, Mark 4, and Mark 5 (ATG), and MORE by another private company, Dr. Neumann Consultants (DNC). These review stations included automated review functions such as missing scene check, display of alarms scenes, motion review, and authentication.

The early 1990s also saw the introduction of the first active sealing system, the Variable Coding Sealing System (VACOSS). Designed to actively record opening and tamper events, it allowed the sealing of nuclear materials while giving the operator the opportunity to open the seal at declared events and then to re-seal the materials without inspector presence. In combination with video surveillance, seals assured that no undeclared activities took place and no materials were diverted. VACOSS was the result of an attempt to interest large commercial entities in the safeguards market in order to broaden the supplier base and to lower the cost. Unfortunately, because the safeguards market being too small for large-scale, automated production this and other attempts did not work out in the long run.

Another example is the IAEA's attempt to interest large Japanese electronics companies in developing and producing an automated reader for the Cobra passive sealing system (originally designed by SNL). Many companies responded when the IAEA called for an introductory meeting. After the technical details were described one representative asked how many units would be needed. The answer, around 200, was immediately followed by the next question: 200 a day? When the IAEA representative shook his head in response, half the meeting participants left the room. When the next question, 200 per week, was answered in a similar manner, half of the remaining representatives left. After the IAEA representative clarified that two hundred units would be the total number ever needed, only a single person was left in the audience.

Analog to Digital—Coping with the Data Flood

In a joint cooperation between Euratom and ATG for European Community use, the first digital surveillance system, GEMINI, was introduced for safeguards in the early 1990s. A few years later the IAEA issued its own procurement request for a digital system and selected the DCM-14, developed by DNC and the German Support Program. With the DCM-14 it was suddenly possible to digitize the data output of an analog camera into digital images, apply compression and authentication, and encrypt data if necessary. The DCM-14 also produced more information than any other safeguards system before it.

The combination of scene-change and alarm-triggered low PTI surveillance systems with continuously operating and data gathering NDA systems caused a data explosion. While data reduction mechanisms (e.g., front-end scene-change detection) were available, the IAEA opted not to delete any data but to apply advanced data filtering and review tools. Originally designed for the GEMINI system, the General Advanced Review Software (GARS) became the standard review application of the IAEA. GARS allows automated technical review of image and radiation data (authentication verification, low contrast, missing scene, black image, alarm events, etc.) and rapid review of safeguards relevant data.

Digital output that could be authenticated and time stamped inside a tamper indicating enclosure allowed images to be securely transmitted to local server stations that saved data on removable storage media waiting for the inspector during inspection visits. Multi-channel systems were designed with the safeguards relevant information conveniently consolidated in a centralized location regardless of the accessibility of the camera. Special application cameras such as underwater, portable, or extended battery surveillance systems followed shortly after.

The availability of safeguards relevant data in digital format, sophisticated encryption algorithms, and secure communication channels at affordable prices (e.g., phone line, ISDN) offered a new method of making information available for safeguards review: remote monitoring. In 1996, the IAEA initiated its Remote Monitoring Project (RMP) to define the boundaries and requirements for a remote monitoring infrastructure for safeguards use. By 2002, some thirty-three systems with seventy-one surveillance cameras were operating in remote monitoring mode worldwide.

The advantages of remote monitoring are straightforward: remote transmission makes data available on a regular basis (e.g., daily) and safeguards relevant events can be reviewed more frequently than with inspection visits to facilities with unattended safeguards equipment, which occur three months or more. Technical problems with the instrumentation become apparent in a much more timely fashion, and the communication link allows for troubleshooting and corrective measures. This means a reduction in time and travel expenses and less impact on the routine schedule of facility operation. Use of remote monitoring also means also that data security and integrity are of utmost importance during the transfer and that recovery measures must be in place and available for cases of unexpected, perhaps extended, loss of communication.

By the early 2000s, the IAEA still had to cope with a broad set of instrumentation standards that needed to be maintained, updated, serviced, and replaced. At one point in time, a total of eleven different video surveillance systems were in use, ranging from old systems waiting to be replaced with new standards to specialty systems used in a limited number of applications. Member state sponsored systems that were domestically developed for safeguards and then donated to the IAEA with the expectation to find a place in the family of safeguards systems were also in use. One prime example of how domestic developments turned competitive is the development of a replacement of the aging VACOSS seal in the late 1990s. No less than three systems were developed in parallel, forcing the IAEA to fully test and evaluate all three but only select one, the German Electro Optical Sealing System (EOSS) as the new active sealing standard. The remaining two have limited or even no application outside of safeguards' meaning the development effort has gone to naught.

At that time, the importance of conducting vulnerability assessments (VAs) by a third party was recognized. During the development of the three seals, VA teams performed assessments during the development process to assist the development teams. This process became an important part of the selection process. Since that time, VAs are mandatory for all new developments. No new equipment is authorized for routine inspection use without positively passing a VA.

At the same time, nuclear weapon states like Russia and the United States agreed to place weapons-grade materials under voluntary safeguards. Under this agreement, facilities in the United States were using a domestically developed electronic seal utilizing radio frequency technology (the T1 Seal, developed by SNL) to monitor storage areas. The system was later upgraded to become the first implemented Remote Monitoring system in a weapon state.

By the late 1990s, the IAEA had 120 different system types authorized for safeguards use including gamma ray spectral systems, neutron measurement systems, spent fuel measurement systems, surveillance systems, electronic sealing systems, and unattended radiation monitoring systems.

Irradiated fuel bundle counters had been in operation in CANDU facilities since 1970, followed by the first major unattended radiation monitoring system for core fuel in 1989. By the end of the millennium there were more than eighty unattended radiation monitoring systems in operation in forty nuclear facilities in more than twenty countries, and unattended radiation monitoring was firmly established as a significant contributor to the efficiency and effectiveness of safeguards approaches.

More and more facilities were placed under traditional safeguards, calling for instrumentation set-up and installation. To support the growing complexity and quantity of equipment preparation, the U.S. Support Program decided in the early 1990s to fund the permanent presence of equipment manufacturer contractors embedded in the IAEA. The milestone for the invention of factory support at the Agency might have been a meeting at the 31st Annual Meeting of the Institute of Nuclear Materials Management (INMM). The head of the International Safeguards Project Office (ISPO) that governs the U.S. Support Program inquired in a side meeting about any known issues regarding the warranty of instrumentation delivered to the IAEA. When he was informed that generally, by the time the IAEA unpacked and fielded equipment, the warranty had long ran out and that there therefore were no issues, he initiated the first support contract. The program was so successful that it is still in place today.

The Next Generation—A Look Ahead

With the beginning of the current millennium, it became obvious that the DCM-14 was approaching the end of its lifetime. As crucial components began rapidly disappearing from the market and newer, more attractive technologies became available, the IAEA initiated the development of the Next Generation Surveillance System (NGSS). In an unprecedented effort, the IAEA reached out towards the safeguards community to gather safeguards experts to define the user requirements of the new safeguards system. These experts came from support programs, research and development institutions, the private industry, various national safeguards authorities, and included representatives from other related industries.

And the community responded. During a week-long workshop in 2003, a large group of experts not only defined the operational parameters of the new surveillance system but in doing so defined the next generation of safeguards systems. Rather than following the dogma of different sensor disciplines operating independent of each other and only communicating in very specific circumstances (e.g., an active seal or an NDA monitor triggering a camera), the group of experts recommended the use of NGSS to standardize data management, communication protocols, data storage and transfer, and review of all disciplines, including NDA, surveillance, seals, and even emerging sensor technologies. The development of NGSS was initiated in 2005 as an unprecedented joint effort of two private companies (ATG and DNC) with the support of two MSSPs (U.S. and German). The first prototypes are expected to be available towards the end of 2007.

The 1990s saw the implementation of the Additional Protocol, which expanded the inspection rights of the IAEA to undeclared facilities and undeclared locations in an effort to strengthen the completeness of declarations analysis. By the early 2000s, this policy development had reached the instrumentation implementation level. A multitude of research and development efforts are underway to prepare the IAEA and provide instrumentation in areas such as Satellite Imagery, Wide Area Monitoring, Nuclear Forensics, or Environmental Sampling (already introduced in the early 1990s).

But the Additional Protocol bears another impact on the instrumentation used by inspectors. Visits to undeclared facilities or to undeclared locations at declared facilities under complementary access (CA) leave the inspector outside the established traditional safeguards regime where measurements are used to verify existing declarations. Because CA inspections and visits to undeclared facilities do not have this benchmark, a different set of NDA and sensor instrumentation is needed. Also, sensor analysis results should be available in real-time or near real-time to give the inspector the opportunity to investigate certain areas more carefully while he is still on-site. Lastly, it would be beneficial for CA inspections if sensor and analysis data could be immediately sent off to the IAEA or other sites for instant, additional analysis and if further instructions could be immediately sent back to the inspector.

The IAEA has long since recognized the need for these capabilities and is pursuing their implementation, keeping the need for portability, ruggedness, standardization, and communication ease (the very same goals of the very early safeguards) at the forefront of its considerations. Similar to the approach of NGSS, the agency reaches out to the international community through workshops, conferences, and the newly implemented Novel Technologies Program to identify synergies and find the right technology mix for new challenges. Of one thing the international safeguards community can be sure when looking ahead: the next five decades will be at least as interesting as the first.

Information Management for Nuclear Verification: How to Make It Work in a Sustainable Manner

Jacques Baute
Director of Information Management, Department of Safeguards, International Atomic Energy Agency, Vienna, Austria

In the last decade information and its management has become a key component of everyone's environment with the exponential development of the digital world, both in the professional and private arenas, and the even more spectacular development of telecommunications and associated portable devices. But perhaps nowhere else than in the area of international security has the need for extended data collection, advanced information evaluation and analysis, and proper dissemination of pertinent knowledge be more demanding, before the challenges identified at the end of the twentieth century.

Over the years, safeguards verification has developed an information-based approach that is embedded in the definition of today's integrated safeguards. However, more progress is needed to ensure the mastering of that complex raw material called *information* and make sure that all aspects of it benefit from the technological breakthroughs.

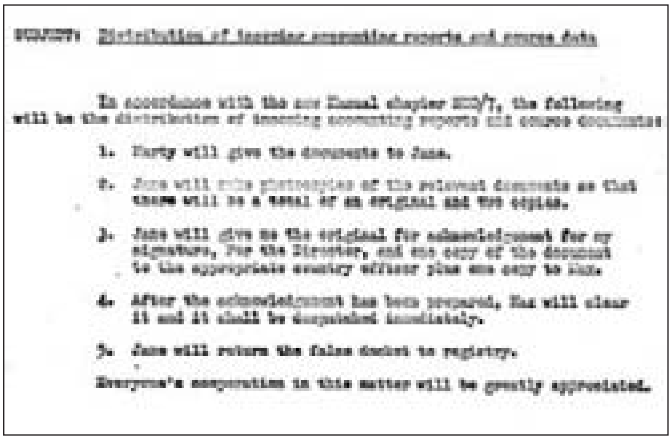
This article will review the progress made from the early days of nuclear verification, review lessons learned from the weaknesses observed through the decades, and propose additional steps to ensure that, as often stated by its Director General, the "IAEA remains ahead of the game."

A Bit of History

When the International Atomic Energy Agency (IAEA) was created fifty years ago, as the realization of U.S. President Dwight D. Eisenhower's visionary "Atoms for Peace" speech to the UN General Assembly in 1953, it is certain that the world at that time had not imagined that information and its management would become an essential tool to support the agency's endeavour to "ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose," as stipulated in its statutes.[1] Neither were computers seen as central to any business, as they are now, nor were the agency's activities foreseen to become "information-driven."

How interesting it is to note the extent and conviviality of information processing, as defined ten years later (November 13, 1967), in an interoffice memorandum addressed to all offices of the Department of Safeguards and Inspection (see Figure 1).

Figure 1.



However, following the entry into force of the Nonproliferation Treaty (NPT) on March 5, 1970, and the subsequent publication of the first version of INFCIRC/153 (the structure and content of agreements between the agency and states required in connection with the NPT), in June 1972, "The management of the Department of Safeguards and Inspection early recognized that a computer-based nuclear materials accountancy system should be developed as a possible alternative to manual accounting and subsequently allocated some manpower for that development."[2] A group of about fifteen staff, the Automated Data Processing Task Force, was then created and soon renamed the safeguards Information Treatment Unit, reporting to the Inspector General. On March 1, 1977, a Division of Safeguards Information Treatment (SGIT) replaced the former unit, in a department now named safeguards, under a deputy director general, with principal functions "to be responsible for the handling of all safeguards data, including input, treatment, storage, and output."

Located in Vienna's Grand Hotel, on Kärntner Ring, a sophisticated remote job-entry station was established, a bathroom where the bathtub was used to collect endless printouts. Communication from humans to computers was through the then traditional eighty-column punched cards, batch processed, and locally generated out of paper declarations. When the brand new ADABAS data management system became operational by late 1978, the total number of nuclear material accounting records had reached about 100,000 (today, the only processing of nuclear material accounting declarations, leaving aside all other aspects of information processing, accounts for 2.5 million records a year). Soon, "big declarations" from Japan and Euratom started to come on 2,400-foot magnetic tapes, while floppies, CD, and e-mail attachments slowly took over. On a disappointing side, who would believe that still today, some major countries provide their declarations on paper for the agency to process manually into its system? Of course, scanning and optical character recognition (OCR) has replaced punch cards, but would only work well when print quality was good.

The autumn of 1979 saw the move of the agency to its current location in the newly constructed Vienna International Centre. In these new premises, information treatment developed drastically from its initial purpose of declaration receipts and acknowledgements, to the handling of all relevant safeguards data, such as state-declared design information and accounting reports; inspection reports and other inspection working papers; results of analysis of samples and NDA measurements; central operation, maintenance, and development of hardware and software within the department and to be responsible for communication with member states on nuclear material accountancy matters with the aim to foster worldwide standardization thereof. Retrospectively, more could have been made of the standardization process, particularly, had we known of the emphasis on analysis that was to come!

By 1991 and the discovery of Iraq's clandestine program, safeguards verification and its information management had developed a good ability to cope with declarations and implement the adequate verification program aimed at verifying the correctness of declaration.

This approach including the thorough analysis of nuclear material accountancy reports, field activity and proper sample analysis and interpretation led to the significant result of spotting the anomalies of the initial declaration of the Democratic People's Republic of Korea. Unfortunately, the nature of the approach, then thought to be adequate by the international community, had enough loopholes for Iraq to begin a clandestine nuclear weapons program and remain undetected for a decade. The international community was convinced that states, which had signed the Nuclear Nonproliferation Treaty (NPT), would remain committed to their engagements, and thus, the agency's role should be restricted to the verification of declared materials and installations. The mistake was to forget that there can be no meaningful verification without measures aimed at detecting whether a state is trying to deceive the system by conducting undeclared activities.

Addressing these loopholes—that is, developing the lessons learned from the initial discovery of Iraq's undeclared program—was the main objective of the 93 + 2 program that led to the approval in 1997 of the Model Additional Protocol. In terms of information, it dramatically broadened the scope of information and access to be provided to the agency in the context of nuclear safeguards verification. Not only was the scope of declaration significantly extended, but new sources appeared, such as open sources, based on the observation that, had the agency been able to put together and analyse information from an extended declaration, draw on open sources quite numerous in the late 1980s about Iraq's apparent intentions and supported by member states who, at that time, had not yet realized that the agency could make good use of sensitive information, the world would not have had to wait for the invasion of Kuwait to address the issue of a clandestine nuclear program in Iraq. The 1990s displayed a growing number of sources of information, out of which the agency would be able to start to derive its understanding of a whole country, instead of limiting its knowledge to declared material and facilities. Furthermore, the addition of new technical tools such as environmental sampling, utilized more and more over the decade, and high-resolution commercial satellite imagery, first available in late 1999, reinforced the role of information in drawing safeguards conclusions. In some ways, the 1990s appear to be the years of a spectacular information collection enhancement for safeguards verification. While at the same time, the explosion of the use of personal computers and associated networks triggered improved information dissemination. This may not be alien to the fact that the division was actually renamed Division of Information Technology by 1997.

Well into the first decade of the twenty-first century, and a Nobel Peace Prize later, the IAEA has become, and needs to remain, a reference for the assessment of nuclear proliferation issues. As recorded by member states in the IAEA's current Medium-Term Strategy, the major objective of the agency's nuclear verification mandate is to provide credible assurance to the international community that states are honoring their safeguards obligations. Information management has taken over from information technology, information treatment or data processing, with a responsibility within the agency's objectives aimed at the generation and preservation of the knowledge needed by the department. Collecting, evaluating, analysing, structuring, securing, and disseminating the adequate information at the right time to the right actors are the numerous facets of modern information management.

Modern Sources of Information

It is important to highlight the fact that the IAEA is the only place in the world that can bring together the extent of information it has access to. If open sources are there to be collected by anyone, combining them worldwide with detailed state's declaration and inspection and other in-field activities results provides the agency with a unique position and responsibility.

Their Nature

International verification starts with a state's declarations. The evolution of these declarations, since the beginning of nuclear verification and the associated problems and solutions implemented, was well discussed in a paper presented at the last safeguards Symposium.[3] State-declared information is and will remain a critical and essential component of safeguards-related analysis. The amount of available information has increased greatly over the past fifty years, and more particularly in the last fifteen years, following the reflections prior to and implementation of the Model Additional Protocol (INFCIRC/540 (Corrected)). At the same time, challenges have arisen with regard to improving the quality of the data and reducing the complexity of handling the information. While the analysis of state-declared information has progressed far beyond that performed in the 1970s, more progress is needed in that traditional area, starting with enhancement of states' systems of accounting for and control of nuclear materials (SSACs) and the streamlining of the agency's information structure, that has resulted from legal evolutions and *ad hoc* arrangements with states, rather than design for analysis. Assessment of the correctness and completeness of states' declarations remains the overall challenge for the drawing safeguards conclusions.

The results of in-field activities, such as inspector observations, and of technical monitoring activities, such as video monitoring as part of containment and surveillance (C/S) measures, provide a wealth of safeguards relevant information for the IAEA. The implementation of new types of access that differ from the traditional verification of declared information, such as complementary access and confidence building visits, or the flow of information derived from the use of advanced technologies, such as environmental sampling or remote monitoring, provide remarkable opportunities to reinforce the effectiveness and efficiency of the IAEA safeguards system. However, they also generate new challenges with regard to the handling of the information produced. How can information of such different nature and actually so overwhelming in terms of amount be made accessible when needed, i.e. now and in some unpredictable future?

As part of the measures developed in the 1990s to strengthen the IAEA safeguards system, new information collection methods were developed, in particular from open sources available to anyone. Again, open sources can be overwhelming (vast quantity of information, multiple languages, information origins, from news media to scientific and technical literature),[4] unreliable (open sources can be based on pure political agendas and not on factual reporting), and *expensive*, such as that from commercially available satellite imagery or from scientific libraries. In some instances, the IAEA may be able to benefit from third-party information, provided on a voluntary basis, either on sensitive cases such as in the case of Iraq, albeit with the additional challenge of source sensitivity, or in the course of addressing new challenges, such as the more recently identified threat of trans-national proliferation networks.

The Challenges They Create[5]

Historically, paper has been an unavoidable source of information that unfortunately buries more of it than it displays. What is the usability of dozens of notes to files, inspection reports, even if well detailed, when a quick answer is needed for taking some action? What can be realistically expected when a key element of information that could contribute to resolving a critical question or prevent a costly action is actually buried among metres of archived reports stored on shelves, if not locked in a cabinet with little access to anyone who would need to know? Little can be expected when the IAEA has limited resources, for instance, for allowing new staff members to develop their own research on a specific topic, before they become fully operational, as can be done in the academic world before the development of a Ph.D. thesis.

Although progress has been made in terms of receiving already computerized information (e.g., state declarations, open source *harvest*, pre- and post-inspection notes, experts' reports), textual data can be as overwhelming as paper-based information, as the result of the historical development of very specific types of independent databases, the immaturity of IT development and the need for increased security measures. Such problems are not unique to the IAEA and are being addressed by other organizations, administrations, and companies (a gold mine for Enterprise Resource Planning providers, for instance). The fact that disconnected pieces of information, recorded for time-specific and motive-specific reasons, should be used for overall, all-source information analysis, presents an interesting challenge. Moreover, the non-textual data generated from cameras, sensors, site layouts, design information, satellite images, ground photos, sample analysis graphics, etc., while providing invaluable additional information, also create an additional burden for the development of new solutions to link and access these resources.

Last, but not least, is the most volatile support for information: the human mind, which is often the repository of details that can make the difference between addressing an issue in a timely and cost-effective manner, or spending an unreasonable amount of resources and time to "reinvent the wheel," or even worse, overlook a problem because a few individuals are aware of the information but are unaware of its significance. The "age pyramid" of the nuclear community and the lack of effective knowledge management are greatly impacting the population of verification specialists, including inspectors, given the spectacular turnover that the IAEA Secretariat will face in the next few years. How many individuals who have recently retired, or will be retiring in the next few years, are experts with eye-opening experience, such as the case of Iraq's weapons program discovery in 1991, that of South Africa and its voluntary nuclear disarmament, and ongoing IAEA cases such as the Democratic People's Republic of Korea (DPRK) and Iran? All too soon, the IAEA will not have available many inspectors, and other critical staff members of the Secretariat whose experience has helped to make its nuclear verification activities what they are today. Are we doing enough in terms of knowledge management and do we have the right tools and methodologies to ensure proper transfer of experience to the newcomers from the old timers?

The overall characteristic of safeguards relevant information is that, on the one hand, its quality is weak, lacking sufficient comprehensiveness to ensure that conclusions are based fully on facts and leave no room for unwanted, opinion-based conclusions. On the other hand, the quantity of information is overwhelming. Can the information systems that will be implemented in the next few years deal appropriately with all these challenges?

From Data to Information and Finally Knowledge

Data

In the agency's case, raw data are collected from the multiple origins listed earlier: state-declared information from member states; open sources obtained through locally developed methodologies; satellite imagery through commercial contracts. In-field activities also provide raw data, be it from the inspector using a computerized inspection report (CIR), bringing back samples to be analysed, or the camera or other sensor installed in a facility.

The characteristic of data is that rarely do they represent information unless some effort, sometimes significant, has been put into them. An important parameter for turning data into information is the necessity to have them processed by adequate expertise and experience. How damaging for the credibility of the inspection regime if, for instance, overhead images are not processed with the most professional eyes and lead to unreasonable access requests!

Information

Information is derived from data when they are validated and put into context.

On states' declarations, data have to go through mandatory quality control and often necessary re-formatting to be later accessed in a reliable manner. How many of the data provided suffer weaknesses in quality, include historical tricks to the computer system that need proper re-evaluation? Open source data can become information when their credibility is assessed to be sufficient to warrant being part of the elements to be considered as a component of future state evaluation. For instance, the explosion of blogs broadcasting unverifiable statements adds to the not-to-be-overlooked possible political bias of classic news media. The pixels and shapes of satellite imagery are information only when they become the image of a facility described with its location (geo-coordinates), delimitation, name and functions.

The circulation of information is an essential component for the effectiveness of an organisation such as the Department of safeguards. Information technologies have changed the order of magnitude of the information available to whoever needs to make a decision, be it a daily low profile action or a major conclusion with broad implication on the future. Today's adequate information circulation includes at least 24/7 network access and proper security that will block access by unwanted people, and prevent the loss of information, or suspension of computer operations (the classic confidentiality-integrity-availability components of information security). Unfortunately, providing all the information that's available in an inconvenient manner might actually be counterproductive: too much information is equivalent to incomplete information; to put it simply, not all of it can be assimilated in the time available. That may be a triviality, but it is too often forgotten: by the addressee of the information who feels that something might be hidden if access to all is not provided; by the provider of the information who wants everybody to know what has been learned, even if it does not really matter.

The key question, actually, is: how can we prevent information extracted for data (i.e., the signal extracted from the noise) to return to data, as the amount of it becomes so overwhelming that it is lost again for the final user? The answer is simple: information management should reach the goal of generating knowledge, not only information, while also preserving the source of it.

Knowledge

Knowledge can be seen as information that has a purpose or use. In other words, in the context of the agency, knowledge is the extent of the understanding that is useful for the person (or part of the organization) with a specific mission to conduct, the definition of which always includes challenging time factors. These time factors are of two almost opposite natures: on one hand, there is the need to take action in due time, for instance between two Board of Governors meetings or Safeguards Implementation Reports (SIRs), or more practically, for the inspector to have all the information really needed prior to leaving for an inspection, knowing that only a few hours are available to be best prepared; on the other hand, a piece of information collected decades ago may be crucial to address a sudden hot issue.

The biggest challenge, and subsequent weakness, faced today by anyone in the context of his or her duty is when the associated knowledge is inadequate to make a proper decision, either because the information available is too succinct, for whatever reason that could have been avoided, or on the contrary, information overload dilutes the useful information to the point that it is no longer possible to distinguish it from worthless background.

Before a lack or overload of information, essential added values have to be provided by the technical contribution of experts in nuclear program processes, by the structuring of data defined by the information architects and database administrators, by the functionalities developers provide though the tools able to extract the useful information from the right place and by the "feedback from the field" provided for instance by the inspectors.

Knowledge associated with the ultimate objective, i.e., drawing conclusions, can only be generated after significant analytical processes, which include the fusion of all relevant information available on a topic (but only those relevant) and reviewed by individuals with adequate expertise and experience (the injection of pre-established knowledge called competence). Such processes must lead to an understanding that is strong enough to be transferred to others, including the major stakeholder called the international community, and not contradicted later on by facts.

Taking Action

There is a quote, the variation of which can be found in multiple speeches of multiple cultures and languages: "Action without knowledge is foolish; knowledge without action is futile." As far as information management in the Department of safeguards is concerned, it is clear that its main objective should be the production and maintenance of the knowledge needed to take all nuclear proliferation relevant actions allowed by its statutes and related agreements, and only that knowledge relevant to the mandate.

The ultimate products that the agency is expected to produce are the conclusions with regard to the respect by a state of its obligations, including with regard to the absence of undeclared nuclear material and activities. This demonstration of such negative is the highest possible investigation challenge, knowing that the "absence of evidence" does not equate to the "evidence of absence." All the information-related processes internal to the verification body, as well as those associated with its interaction with the outside world, should lead to an organizational knowledge strong enough to prevent any surprises, as future surprises will be the biggest threats to the credibility of the agency.

However, in no way should the concept of knowledge be limited to drawing conclusions. Well before such actions, knowledge should be optimised to conduct adequate follow up, be it through interaction with member states, actions at headquarters, or field follow up. Punctual actions as well as annual implementation plans (a key component of integrated safeguards) should ideally be based on the most advanced knowledge, not only some limited information or even worse, raw data. How many issues could be addressed simply by allowing the person with the right knowledge to provide the adequate input, prior to any more expensive action? On the reverse side, how many future issues, maybe even embarrassing issues, can be prevented by giving, more systematically, the opportunity to the right competence to review some piece of information?

Even more challenging, knowledge needs to survive the erosion of time: it has to be captured in an institutional mode, not in individuals' brains, destined to vanish with natural or administrative turnover. Unfortunately, even if capture were satisfactorily doable, beyond the piling of hard copies or their scanned versions, time integration only leads to additional burden in terms of overwhelming amount.

The Multidimensional Aspect of Nonproliferation Knowledge

The Assets for Proliferation

Nuclear proliferation is (fortunately) a complex endeavour that requires significant assets. Everything starts with the "political will," which can come from geopolitical tensions, national feelings of insecurity, or attraction to the apparent status of world power for the owner of a nuclear weapons arsenal. Proliferation also requires substantial financial resources. Although a state struggling to find adequate income to feed its population may be less likely to proliferate, history demonstrates that this may not be a valid argument. The very existence of an adequate nuclear infrastructure, comprising specific facilities, adequate energy supplies, and transportation means can be viewed as an advantage for a body conducting nuclear verification activities, compared to the challenges associated with the verification of the development of chemical or biological weapons of mass destruction.

Nuclear materials of specific quality (e.g., highly enriched uranium, plutonium), in the right quantity (kilogram not microgram), remain the "choke point" for justifying without reservation the fact that safeguards approaches focus foremost on preventing the diversion of nuclear materials.

The scientific and technical basis of a nuclear program is necessarily broad and diverse, on the order of magnitude of at least hundreds of workers, if not thousands, with multiple skills—physicists, engineers (e.g., mechanical, electrical), chemists, and skilled and unskilled labor. All told, this group of individuals must possess multi-faceted knowledge required to deliver what the political powers expect. Such knowledge is not trivial. Currently, the amount of information (and disinformation) available on the Internet does not allow one to move forward concretely without an appropriate and significant R&D program.

Unfortunately, in the context of the proven existence of networks of the type discovered relative to Libya at the end of 2003, that aspect needs to be continuously reassessed. Nevertheless, new components such as trade networks, entities like companies and individuals, have to be considered as safeguards-relevant information in order to ensure the agency's credibility in the long term.

The Assets for Nonproliferation

Fortunately for the IAEA as a verification body, all of the assets needed for nuclear proliferation are sources of indicators and signatures that can help to detect possible undeclared nuclear activities. For such detection, the IAEA also has at its disposal significant assets. Member states have provided the IAEA with the relevant policies, financial resources and legal instruments, such as the definition of the IAEA's rights and obligations and their temporary reinforcement through, for instance, resolutions of the IAEA Board of Governors, or the UN Security Council. In addition, member states have assisted the IAEA in the development of staff competence, through training and technology support that reinforces the IAEA's capabilities.

The primary asset for the IAEA as a verification body is the legal right for access in the field, whereby inspectors can legally enter a state to inspect installations, inventory relevant materials, monitor facilities and interview operators and other counterparts. This access represents an exclusive i that the IAEA possesses and that no state acting alone can possess, except in very infrequent and often politically sensitive situations. The international nuclear verification community has also developed mature measures, from techniques to methodologies, building on decades of experience and on the specificities of nuclear materials and nuclear programs. Information management improvements should first seek to make the most of all these in-field specific assets, given that this is what gives the IAEA the possibility to "make the difference" in the nonproliferation world.

This is reinforced by the fact that the activities internally conducted by the Secretariat may represent the areas where significant progress can be achieved the soonest, since these activities do not pose the difficulties associated with obtaining member states' unanimous support for new legal arrangements or their acceptance of additional voluntary undertakings when being inspected. While the IAEA, with member state support, has developed and continues to elaborate new safeguards concepts, improved methodologies and advanced technologies at its headquarters, progress in information collection, analysis (including the need for consolidation), evaluation, and secure dissemination offer valuable opportunities to improve the effectiveness and efficiency of the IAEA safeguards system. It may actually be worth repeating that the IAEA is actually the only place in the world that can bring together and analyse the extent of information it has access to.

Structuring the Information

From the inspector's observations at a location to the imagery analyst's image enhancement, from the review of the frames of the remote monitoring camera to the establishment of the picture developed by the open source analyst, from the recording of the details of a piece of equipment to the footprint of activities exhibited by particle analysis, all are detection means resulting in information that will, in some ways and at some point in time, contribute to drawing the expected conclusions, or at least to developing an action plan, provided that the right expertise is able to process it and provide the adequate level of added value. Given the complex nature of all elements of information available, as well as their amount, making it all available would only leave us in the middle of the river. The time when conclusions could practically be drawn out of a few tables called PIL, ICR, and MBR (the nuclear material inventories, changes, and balances) are long gone. Actually, gone too is the time when, along the way, we all learned knowledge could be transferred through bi-dimensional media, called documents or black boards. How long would a report be that contains all the details needed to draw conclusions on properly documented facts? How many reports would actually be needed, with redundant information, for all contributors to participate in providing a collective assessment, one looking at existing facilities, another looking at the coherence of program components, another at possible contributions by a black market, etc.?

The key question is: how much time does a needed contributor have to make the most of the information available and deliver added value? Is that time measured in minutes, hours, days, or months? There is a single answer: time, as well as resources available, will always be too limited! The only solution is to make sure that information is structured in a manner that will allow access to any available information from multiple angles, those needed by the multiple expertises and detection means to be applied.

Given the importance of in-field verification, it goes without saying that the primary adequate structuring axis should be geographic. All known assets subject to verification are located somewhere, which may be the destination of the next inspection, which can be prepared through remote virtual inspection using satellite imagery, assisting the traveller by providing all but only that information related to the destination, building up the inspector's knowledge by making the most of the few hours available between two different destinations. Can we imagine that in five years from now, Geographic Information Systems (GIS) will not be the preferred way of access to information? It is clear that the effort necessary to geo-reference all information to make it available through GIS should not be overlooked.

Another extremely important way of mapping a nuclear program is through program components. An extended and refined physical model covering all possible activities, from the mine to the weapon, including its potential delivery systems, must be allowed to assess the coherence of its understanding. Being able to derive "coherent pictures"[6] of states' nuclear programs and capabilities is a *sine qua non* to draw credible conclusions.

Key materials, nuclear or non-nuclear, and equipment, single use and dual use, provide essential angles for approach, hence input, to analysis. Inventories, transit matching, material balance, particle analysis, forensics through impurities identification, all are activities centered around nuclear materials, the consolidation of which is essential. Understanding destination and use of non-nuclear materials or dual use equipment can provide key indicators or permit dismissal of potential indicators of a possible undeclared nuclear program.

State evaluation cannot solely focus on technical or physical elements but also need to integrate other parameters, such as administrative arrangements (how credible is an SSAC, e.g., do we really receive a countrywide declaration?), entities that are involved in nuclear fuel cycle relevant activities, from research to potential production, legal, trade, and commercial arrangements (or lack of) that may prevent or facilitate proliferation paths. Understanding cross-border trade networks better[7] is an additional approach needed to reinforce the IAEA's overall ability to remain a trustworthy source for the assessment of nuclear proliferation issues. Such considerations are not standing alone but in intimate interconnection with all elements listed previously.

Last but not least, time is a factor that adds a final fundamental axis to the information space: not only do we need to know what we know today, but there is no credible analysis of proliferation issues without securing the evolution of the *picture* of a country through time. An issue solved today because of the current limitation of the information may become a major oversight tomorrow when new elements will shed a new light. Even more difficult, while communication between the secretariat and its state counterpart is usually pretty well documented, the productive debate between internal contributors is usually so volatile that it vanishes as soon as an outcome that may only be of a temporary validity is decided. How to capture through time such analytical added value adds a component of complexity to the information to be captured in a properly structured way.

The Way Ahead

As it has done over the last decade following the conclusion of "Program 93+2" for strengthening safeguards and the adoption and implementation of the Model Additional Protocol, the IAEA will continue to ensure that it makes the most of its information resources.

With regard to information collection, *better, broader,* and *deeper* are the key words. Better information collection involves improving the quality control of declared information, with the provision to states of enhanced declaration computerized tools, training SSACs' personnel to enhance quality assurance, assessing more reliably open sources information credibility, and adding new technical expertise and information tools such as information extraction to identify "the signal within the noise." Broader information collection relies on the identification of possible new sources, for example through the development of access to Web-based information in less common languages; through assistance from recruited experts; through the implementation of machine translation tools; through the use of commercial satellite imagery that can be appropriately analyzed with adequate internal skills, including for high-resolution radar; and/or through the growing awareness of proliferation challenges among commercial companies so as to obtain information that was simply discarded in the past (e.g., commercial enquiries ignored as soon as company ethic and national export control would prevent further action). Deeper information collection relies on the ongoing identification of current limitations, including a gap analysis of the required expertise in relevant technologies and improving access to information not yet fully reachable via standard tools. For instance, only a small fraction of the information posted on the Internet is actually accessible through typical search engines.

Making all information available, on a need to know basis, demands integrated information architecture, from the digitization of the historical paper heritage to the consolidation of a complex infrastructure, both in terms of databases and hardware. Now-mature concepts of a business-driven architecture[8] (i.e., a service oriented architecture, SOA) can provide tremendous opportunities for optimising the timely dissemination of information and knowledge to those who need to know while significantly decreasing the maintenance costs of state-of-the art systems. At the same time, enhancing security policies and technical solutions will allow the IAEA to maintain the trust that states have in its ability to respect confidentiality undertakings.[9] Owing to member state recognition of the need for these efforts and the provision of special regular budget funds and extra budgetary funds, the IAEA has an exceptional opportunity to move forward at a much needed accelerated pace. The ISIS (IAEA safeguards Information System) Re-engineering Project (IRP)[10] will deliver a fully integrated information system that would increase both the effectiveness and efficiency of the Department of Safeguards.

Challenges for the Future

As indicated, the agency, with the support of its member states, is taking significant measures to tackle the complexity of today's information heritage, a product of the development of five decades of instruments aimed at reinforcing the nuclear-related aspect of international security, in parallel with the explosion of the digital world. Will this effort, including the financial aspect associated to it, produce a long lasting reinforcement of the agency's effectiveness and efficiency? Certainly, provided that a certain number of issues are properly addressed.

First of all, the disparity of the population dealing with nuclear proliferation information is extreme and will even be larger in some near future. As referred to in the education world, the announced arrival of the generation of "Digital Natives" (those children who learned how to use a computer before they learned to read) will put additional pressure on the world of "Digital Immigrants" we all are. How can we deliver information management solutions that will be good enough to make the most of everyone's competence and maintain everybody's motivation? This may sound like quite a futuristic issue but it will happen soon. In any case, even in the world of the "Digital Immigrants," we already have to reconcile the needs of those whose understanding of information management is practically limited to having available a document management for electronic versions of papers (the digital version of the traditional filing room/file cabinet/drawer/hanging folder/stack of paper), assisted by text retrieval capabilities; those who discovered the charm of sorting out and filtering provided by spreadsheets and may call a database a series of unrelated tables; those who already experimented the power of relational databases without having fully mastered the issue of information integration. Unfortunately, as it exists for geographic immigration, the perceived threat generated by the change in profile of one's surrounding can sometimes lead to some kind of "Digital Racism" or "Digital Xenophobia," phenomenon that may prevent obvious progress towards a new environment, particularly in a context where making information more available through modern information systems is felt by some as a potential loss of their long established power.

Another major challenge to cope with is that making information "available to all" does not mean that all are capable of handling it in a productive, if not a non-destructive, manner. The old processes where the expert was a choke point had a certain advantage: the information filtered by the expert was bound to have benefited from the added value of his competence. We'll need to put in place a means to identify the nature of the expertise and experience imperatively needed for the computer to deliver the information the adequate way. As Pablo Picasso used to say, "Computers are useless. They can only give answers." We need to make sure that the right questions have been asked before the answer is provided by the machine. Only smartly implemented processes can ensure proper results.

Directly correlated to availability, security has been a developing challenge that often remains a mystery to many key players. The most traditional "Digital Immigrants" often see hard copies as the only secure way to handle the most sensitive information. Actually, for paper or electronic information, security is built on policies, processes, and cultural awareness, knowing that the technological solutions exist today. Of course, the sophistication of these solutions can only be continuously growing, in a world where the agency has acquired a profile that makes it a target of interest, for political or *fun* motivations. Lots of work and associated resources will be required done to make sure that one day, we won't regret to have worked well at information availability but got caught of guard on information confidentiality and integrity.

What we may not have measured yet is the consequence of the new technologies, particularly in the area of communications that will allow information to flow anywhere in no time. Of course the Internet has become nearly everyone's tool (poor librarians!) as a vehicle for quick answers, telephone and its PDA extension keep us in touch with our counterparts and in control (let's dream) of our agenda wherever we are. However, in the solutions we are now putting in place, we need to anticipate the soon to come needs without overlooking the additional challenges associated with them. Solutions, such as "smart clients with off-line capabilities," will allow travelers to benefit from a "portable interaction" with headquarters information and tools, even in a plane without telephone service. But, when dreams include "same access from the field as that from headquarters," everybody understands well the advantage of not having to go back to headquarters to follow up immediately an issue, but what does that mean in terms of taking also into account the security aspect of information transfers? Even more complex, the access to information provided by technical sensors needs to be completely reassessed. The traditional separation between hardware, communication tools and the management of the resulting information is getting less and less valid, when devices are everyday moving into more integration (just think digital camera and mobile phone). The technical solutions of tomorrow will have to be thought through, planned and implemented in a completely new spirit, from all counterparts, from the inspected party to the technical implementer. Project management relying on advanced competencies and supported by best practices will be part of the values that will need to be shared by all counterparts if technology progress is to have serious impact on efficiency and effectiveness of verification, keeping in mind that never will the agency have the resources to come close to the world of national defense where integrated solutions are usually developed.

Conclusions

Since the creation of the agency, the extent of information relevant to safeguards and its role has grown so dramatically that today, we are talking "information-driven safeguards" and information management is at the heart of modern nuclear verification. Over the past fifteen years, in particular since the discovery of Iraq's clandestine program that highlighted the need for focusing additionally on the detection of undeclared activities, the IAEA has moved significantly away from its traditional role of nuclear material accountancy *auditor*. The challenges posed by safeguards-relevant information and its collection, analysis, evaluation, and dissemination suffer no comparison with the initial inception of data processing, about thirty years ago. Knowledge management has become the overarching objective for information management, if not for the overall management of verification resources.

Through the implementation of processes, measures and tools commensurate with the expectations of the international community, not only should we resolve today the problems resulting from decades of parallel evolution in both the role of the agency and information technologies, but also we should, more than ever, try to anticipate the challenges of tomorrow. Ensuring the generation of knowledge needed to deliver today's expected products (e.g., timely and credible conclusions) has to be combined with guaranteeing the preservation of knowledge through the decades to come (the conclusions of tomorrow will heavily rely on today's knowledge, particularly in the context of integrated safeguards), in a manner that will not appear to be totally demotivating for the generations of verification professionals who are going to join us after being raised in a world of computer entertainment and anywhere/anytime communication.

The safeguards community, from wherever anyone is contributing to it, should always bear in mind that piling layers of traditional solutions, even if they were solutions proven by experience, will not deliver the necessary improvement in effectiveness and efficiency. *Integration* is a key word, for safeguards implementation as well as its associated information management. To that end, we shall all contribute to identifying the risks ahead and work together at defining the innovative solutions that will allow safeguards conclusions to remain credible and the agency to stay "ahead of the race."

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