Integration of Safeguards: The Technological Dimension

Bernd Richter and Gotthard Stein, Forschungszentrum Juelich GmbH
D-52425 Juelich, Germany

ABSTRACT
The integration of INFCIRC/153 and 540 safeguards has two aspects. There are strengthening elements which can already be implemented under the existing legislation, whereas other elements can only be implemented after the entering into force of the Additional Protocol. However, the main thrust of the integration of ‘old’ and ‘new’ safeguards will be a tremendous increase of information treatment within the IAEA. The paper will describe technological aspects of the new Integrated Safeguards and will give some perspectives in which directions technological development and future research should be going.

1. Introduction

The International Atomic Energy Agency (IAEA) has the mandate to verify treaty compliance by applying a safeguards system which relies on on-site inspections and includes unattended monitoring techniques in the non-nuclear weapons states parties to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). Under the hitherto applied INFCIRC/153-type agreements treaty violation is to be detected by the IAEA on the basis of its verification of states’ – complete (!) – declarations on their nuclear activities and materials.
The first treaty violation, which had not been discovered within the existing safeguards system, gave rise to the consensus among the majority of states to extend the IAEA's capabilities towards detecting undeclared nuclear activities as well as gaining assurance on the completeness and correctness of states' declarations. The objectives have been laid down in the Model Protocol Additional to Existing Safeguards Agreements (INFCIRC/540). The implementation of this protocol will be achieved by integrating the new methods with a reduced set of the conventional methods of INFCIRC/153 [1, 2].
The integration of INFCIRC/153 and 540 safeguards has two aspects. There are strengthening elements which can already be implemented under the existing legislation, whereas other elements can only be implemented after the entering into force of the Additional Protocol. However, the main thrust of the integration of ‘old’ and ‘new’ safeguards will be a tremendous increase of information treatment within the IAEA.
The amount of data generated by conventional safeguards techniques such as optical surveillance and radiation monitoring increases, while at the same time the IAEA is additionally obliged to evaluate environmental samples, open sources information, and expanded declarations and to put all the information gathered into one context. Open sources, among others, relate to commercial satellite imagery and public media such as newspapers and TV. Given the persisting zero-growth IAEA budget the IAEA has to enhance its technical capabilities, in order to be able to cope with the challenges.
The implementation of state-of-the-art technologies for monitoring and information processing within the IAEA requires the close co-operation with the Member States Support Programmes towards technological development and provision of expertise, e.g., by the delegation of costfree experts. Moreover, the application of modern low-power consuming electronic equipment has shown that radiation sensitivity has

become an important issue. This does not only require appropriate technical designs but also the expansion of testing capabilities. Technical solutions to reduce the on-site inspection effort aim at remote monitoring techniques, i.e. to apply unattended monitoring systems with remote data transmission from the facilities to the IAEA headquarters. Here, data security aspects play an important role, as it is required to authenticate and encrypt the safeguards data.
The paper will describe technological aspects of the new Integrated Safeguards and will give some perspectives in which directions technological development and future research should be going.

2. Dynamics in Safeguards

International Safeguards are characterised by a strong dynamical element. The international safeguards system started with the design and implementation of the INFCIRC/66-based safeguards system. As 'Pre-NPT Safeguards' this agreement is exclusively related to those nuclear items which are designated for safeguards. Therefore, in principle, it is possible that under this system national nuclear activities lie outside IAEA Safeguards. The system itself has a broad scope, so that not only nuclear material and activities but also, e.g., heavy water can be safeguarded. The next step in the evolution of the safeguards system was the negotiation and implementation of INFCIRC/153 as the safeguards system of the NPT. On the one hand, NPT Safeguards in NNWS require the verification of all nuclear materials as well as activities; on the other hand, the application of safeguards is limited to nuclear material. In addition, the inspectors' access in facilities is restricted to so-called strategic points at which nuclear material is accessible for measurement or can be monitored.

In this evolution one can identify two main directions. The first one is related to extending the scope of safeguards; the second one concerns the element of universality. To begin with one has to analyse the structure of INFCIRC/153. The objective of this safeguards system is the timely detection of the diversion of significant quantities of nuclear materials. This safeguards goal implies a quantitative resolution in time and material quantity so that appropriate conclusions can be drawn by the IAEA. The main elements of the system are accountancy and measurements which allow the Agency to perform these quantitative calculations. The general objective of INFCIRC/153 to verify the correctness of states' declarations is achieved not only by deploying the above mentioned quantitative elements but also by making use of some qualitative features such as those which involve design information verification. The aspect of universal application to all was, in the 'pre-540' time, covered by voluntary offers on the part of the Nuclear-Weapon States and item-related safeguards (INFCIRC/66) by states still outside the NPT.

The new INFCIRC/540 Model Protocol opens the door wider in both directions: scope and universality. As regards the universality issue it has been recognised during the discussions in the 'Committee 24' of the IAEA Board of Governors that all states must be concerned about undeclared nuclear activities, and that globalisation does not stop at the nuclear market. In consequence, there are now different INFCIRC/540 Model Protocols for both NNWS and INFCIRC/66-states which take into account their different boundary conditions. So, one can conclude that, in principle, a new vision of universality has been reached [3].

As regards the scope of INFCIRC/540 the following can be stated. Controlling nuclear materials and activities to reach credible assurance on the absence of undeclared nuclear materials and activities implies a qualitative safeguards system, since these conclusions can only be drawn on a qualitative basis.

All this has to be understood under the inherent realization that an absolute assurance on the absence of undeclared nuclear material and activities can never been reached. The factual situation leads to the conclusion, that new tools and technologies for safeguards are needed to cope with the requirements, especially with regard to the IAEA achieving better assurance.

3. Further Trends for Safeguards

Strengthening the safeguards system through enlarging its scope and reaching universal application relates to improving the effectiveness of the international safeguards system. In addition, there is the need to improve the cost-effectiveness and efficiency of safeguards. This complex problem will be influenced, e.g., by the following factors and driving forces: There is a mainstream development towards saving resources and budgets around the globe which will not stop at UN institutions, and, therefore, also not at the door to IAEA safeguards. Diplomatic circles are asked to discuss and implement such budgetary reductions. On the other hand, integration of INFCIRC/153 and INFCIRC/540 means combining old and new safeguards. This task should be performed with the expectation of reducing overall inspection effort, as already mentioned. Derived from this discussion, it is anticipated that there are possible savings in the future safeguards system.

In contrast, additional IAEA safeguards resources may be required due to the following. The global energy system is still in a process of growing quantitatively as well as qualitatively. There is no evidence that global population increase and energy consumption will be de-coupled. As a consequence of this fact, nuclear energy has a strong perspective, especially under the concept of sustainable development. Presently, there are programmes under way (INPRO and “Generation IV”)[1] which will study innovative fuel cycles and power plants under the aspects of environmental, safety, and economical concerns as well as non-proliferation and safeguards aspects. The increase of national nuclear programmes leads to the need for additional inspection resources for the safeguarding of nuclear materials and facilities by the IAEA.

Future activities in nuclear disarmament or cutting off fissile material production also lead to substantial additional safeguards efforts for the IAEA. In the so-called Trilateral Initiative it is foreseen that the IAEA will verify weapon-origin and other fissile material released from defence programmes in the Russian Federation and in the United States of America. In this initiative the USA and the Russian Federation determine which fissile materials they will submit to IAEA verification. The IAEA should have the right und obligation to verify that fissile materials remain separate from the manufacturing of nuclear weapons.

[1] INPRO (Innovative Nuclear fuel cycle PROgram) and “Generation IV“ are initiatives in the IAEA and USA to identify nuclear fuel cycle and reactor concepts which will satisfy future energy needs under Sustainable Development.

In order for the Fissile Material Production Cut-off Treaty (FMCT) to become effective and efficient, four requirements are of utmost importance [4]:

- Universality:
  The FMCT shall be universally applied on a global basis. This requires accession to both the future fissile material production cut-off and the comprehensive test ban treaties, not only by the present NWS but also by the threshold states India, Israel, and Pakistan as well as by the present NNWS. It is anticipated that India, Israel, and Pakistan play a key role as regards the entry into force of the FMCT. Without these states, the FMCT should not be considered universal.
- Non-discrimination:
  All rights and obligations arising from the FMCT have to be equally applied to all parties to the treaty.
- Irreversibility:
  Fissile material inventories once declared for civilian uses must not be devoted to military purposes, thereafter.
- Transparency:
  The compliance with both the prohibition of fissile material production for military purposes and non-transfer of civilian inventories into military uses must be reliably verified. The kind and scope of the remaining military inventories have to be as transparent as possible.

Also, the following factors are important for the further structuring of safeguards:

- Political and institutional aspects
  One problem of prominent nature is the question as to whether the IAEA, in carrying out its verification activities, should be allowed to differentiate between states while, at the same time, not violating the principle of non-discrimination. There is a challenge by the new protocol INFCIRC/540 towards such a differentiation, since hard and soft factors can influence the practical safeguards implementation. What are the factors that are of relevance in a state? Here are some examples: Fuels cycle specific elements, the rôle/independence of the State/Regional System of Accounting and Control (SSAC/RSAC), and transparency.

  A top agenda item and question of primary importance is to what extent the IAEA should relegate verification activities to the SSAC or RSAC. In this context, it is also of interest to know how far the IAEA is able to implement the tool of quality control of regional or SSAC safeguards.

- Safeguards approaches
  It has already been mentioned that integrating INFCIRC/153 and INFCIRC/540 aims at combining qualitative and quantitative control structures on an equal level. That is a new task for the IAEA and has also to be carefully considered in formulating the evaluations and conclusions in its annual Safeguards Implementation Report.

  Another important agenda item concerns timeliness and detection probabilities. Since the integrated safeguards system presently offers a possibility to obtain credible assurance on the absence of undeclared material and activities, one can consider a reduction of the classical timeliness and detection goals, e.g., from three months to one year for spent fuel and from one month to three months for fresh MOX fuel.

Last but not least, another topic on the agenda is to re-visit other classical safeguards criteria with the intention to adapting them to the new conditions of the integrated safeguards system, also taking into account inspection schemes with random or unannounced character.

The recent terrorist attacks in the USA may lead to the re-consideration of the general verification goal, which consists of

- detection
- deterrence
- confidence building.

The question arises what specific role these elements should play in the future and what importance should be attributed to them.

The second question is related to the element of prevention and how this element can be strengthened.

4. Status of the Development of New Verification Technologies

The IAEA Strengthened Safeguards System will have to be based on improved and cost-effective verification techniques taking into account new facility projects in advanced nuclear fuel cycles. To this end the IAEA had been advised to embark on what has become known as the IAEA Integrated Safeguards Instrumentation Programme (I^2SIP). The objective is to enhance the IAEA's inventory of mutually compatible instruments by introducing the concepts of standardization and modularity, in order to facilitate the design of customized integrated verification and monitoring systems which can operate unattendedly with remote data transmission. This concept will also facilitate implementation procedures, servicing and training for technicians and inspectors [5].

In general, advanced safeguards techniques comprise measurement sensors, optical (or image) surveillance units, seals, and components for the collection of data. As far as safeguards specific requirements are not addressed by the commercial market safeguards specific development efforts need to take place.

In the measurement sector, instrumentation is required with specific sensor heads, i.e. radiation detectors with high neutron counting efficiency at low gamma sensitivity, gamma detectors operating in a wide dynamic dose rate range, high resolution gamma detectors operating at room temperature, and small size detector systems with high sensitivity. In a first step commercially available detector equipment is being screened and tested under realistic conditions for its safeguards appropriateness. In the nuclear electronics sector digital signal processing electronics and data acquisition modules are being developed.

Combining measurement equipment with optical surveillance techniques will yield integrated safeguards systems with new capabilities [6]. However, standardized modules for radiation monitoring systems capable of networking and remote data transmission are lacking. There is an urgent need for the development of modular, miniaturized, digital spectrometer components with data authentication and encryption, which will readily lend themselves to integration with digital image surveillance techniques.

The new digital video techniques allow for the configuration of small to very complex image surveillance systems as well as the integration with other monitoring equipment in unattended systems and implementation of remote data transmission. The issue is whether such systems will have the capability of reducing on-site inspection effort. This is being analysed in a number of remote data transmission field trials performed in various countries under different conditions. Prerequisites are the integration capability of devices as well as data authentication and encryption. Test criteria are reliability in connection with lossless data acquisition and user-friendliness with regard to system operation and data review. A meaningful data review also requires powerful data processing by automatically correlating, e.g., image and measuring information.

In addition to the objective of reducing the inspectors' routine on-site efforts, the use of complex unattended integrated measuring and monitoring systems will allow for decreasing the inspectors' exposure to radiation and, last but not least, reduction of escorting requirements on the plant operators' side.

Development efforts should also focus on low power consumption components, in order to ensure that mains power outages can be bridged using commercially available power backup modules in order to ensure uninterrupted data collection. As a matter of principle, equipment development and maintenance costs should be kept to a minimum by identifying, adapting, testing, and using, as far as possible, commercial-off-the-shelf hardware and software.

As the safeguards market is extremely small, the industry is not able to sponsor safeguards specific equipment development. In addition, the IAEA's R&D budget is limited. Therefore, most of the dedicated technical and methodological development is being sponsored by IAEA Member States. At present, there are 15 R&D programmes in support of the IAEA (i.e. Member States' Support Programmes) including the one sponsored by the Euratom Safeguards Office. The IAEA provides management and evaluation support and co-operates on the expert level as the future end user of the development results.

In order to improve its ability to detect undeclared nuclear facilities and activities, the IAEA is interested in the systematic collection, review and evaluation of open source information on states' nuclear activities in addition to all information available to the IAEA through its safeguards activities. To this end, the IAEA needs support in improving available databases and implementing methodologies of information review and analysis. There is a wide variety of open sources which can be categorized as follows.

Human sources may include inspectors, industry staff, analysts, consultants, university staff, laboratory staff, equipment suppliers, trade association professionals, as well as private contacts at meetings and conferences. Published literature comprises periodicals and scientific journals, reports, books, brochures, patents, news, and media reports. 'Grey' literature refers to company reports, meeting notes, conference materials, and white papers. Electronic media include commercial databases, the internet, and information services. Organizational contacts can be specified as professional societies, lobbying groups, specialized interest groups (e.g. Non-Government Organizations), technology or equipment vendors, and government sources. Remote and local sensing refers to satellite imagery and environmental sampling.

The IAEA's task is not only to acquire the information but also to arrive at a knowledge base. To this end the IAEA has to solve the practical problems of collecting, classifying, structuring, filtering, categorizing, correlating and analyzing the data. This requires the application of appropriate tools which are provided on the software market or have to be adapted in consultation with experts.

Important features in coping with the open source data are credibility, diversity, relevance of user needs, no data overload, problem of missing key data, and the necessity of assessing the relevance and quality of the data.

One particular information source is commercial satellite imagery, which, by itself, is not expected to be capable of detecting undeclared nuclear activities. However, it has a great potential to indicate anomalies which the IAEA will be able to resolve by other means such as special inspections and complementary or managed access. Satellite sensors provide a variety of multispectral information, i.e., images in the visible, infrared, and radar ranges. This information is to be analysed, e.g., to monitor ground activities and changes around nuclear facilities as well as to determine operational characteristics and temperature variations in cooling reservoirs. Development efforts aim at providing software tools for change detection and site characterization using new mathematical algorithms. It should be stated that satellite imagery has been identified to have the widest range of application in verification treaties, i.e., for NPT, Chemical Weapons Convention, Comprehensive Test Ban Treaty, future Fissile Materials Production Cut-off Treaty, and future Biological Weapons Convention.

Another method to detect undeclared nuclear activities is environmental sampling, e.g., swipe sampling inside declared enrichment plants and hot cell facilities, to detect undeclared high enrichment of uranium and plutonium separation. Development efforts are needed to adapt the analytical techniques to the facilities under consideration, provide reference materials, and organize a network of qualified analytical laboratories.

In addition, the INFCIRC/540 Model Protocol foresees environmental sampling of air, water, vegetation, soil, and smears, in order to enable the IAEA to draw conclusions about the absence of undeclared nuclear activities over wide areas. Efforts are required to characterize source terms, model atmospheric as well as waterborne transport of nuclear signatures, and to develop screening methodologies, sampling procedures and analytical methods.

For both satellite imagery and environmental monitoring the advantage of there being no need to perform on-site inspections is not only of paramount importance for nuclear safeguards but also for other verification regimes. The other positive aspect of these technologies is the huge technological future potential and therefore the overwhelming perspectives, e.g., through improving resolution of multispectral satellite imagery or through improved particle analysis for environmental monitoring.

5. Future Trends for Research and Development

Additional research and development needs arise from the impacts of integrating the old INFCIRC/153 safeguards with the new INFCIRC/540 system. These areas are related to:

- Protection of sensitive information
  The additional access which is expanded in scope and space leads to the need to perform managed access and to protect sensitive information. Centrifuge enrichment technology is one example. A second related example evolves from the Trilateral Initiative. Here, the protection of sensitive weapons materials-related information is essential to further implementation of an effective safeguards system.

- Authentication and tamper-resistance
  The preceding discussion addressed the need for unattended and remote safeguards equipment to strengthen the efficiency of safeguards through reduction of on-site inspection effort. An essential precondition for the applicability of this technology is the availability of an improved authentication and tamper-resistance; i.e., the IAEA must have the assurance that it collects authentic information and detects any falsification of the data as well as tampering with the safeguards equipment. Experience has shown that commercial-off-the-shelf systems are not applicable in any case. Normally, sensor heads and data generators have to be newly developed.

- Environmental testing of equipment
  With the implementation of modern low-power-consuming digital image surveillance systems in control areas a new problem has recently been discovered: Single Event Upsets (SEU) induced through neutrons, e.g., from the reactor environment [7]. These events have caused a general reconsideration of the structure of environmental qualification of safeguards equipment. These effects have to be taken into account in the planning and performing of development tasks for safeguards equipment.

- Social and institutional transparency
  As already mentioned there is a need to take into account socio-political aspects in safeguards. One research area could reflect the necessary flow of information and budgets in a country associated with the clandestine development of a weapons programme. Indicators for the detection of such a programme could be gained through open information which could be released, e.g., by institutions which are concerned with the programme and have a constitutionally independent function in the state. These aspects could complement the IAEA's so-called "physical model", which gives technical indications for the development or production of materials and technologies which are needed for a nuclear weapons programme in a state.

- Modeling
  Modeling of inspection strategies, e.g., the impact of unannounced inspections or the connection and interaction of different factors to determine the effectiveness and efficiency of safeguards will become more important.

- Software development
  Especially for satellite imagery, further software development is needed. This software could support the application and implementation of tools, e.g., for

change detection in the structure of buildings or infrastructure, which are of relevance for undeclared activities.

All these necessary research activities have to be performed in an interdisciplinary way. The following different scientific disciplines and technology areas are of relevance [8].

Physics: sensor development, particle analysis, mass spectroscopy, acoustics.

Mathematics: game theory, fuzzy logics, neural networks, simulation.

Electronics: digitization, remote monitoring, data compression, data encoding.

Biotechnology: development of biosensors.

Nanotechnology: microsystems.

Further relevant fields are satellite technology, chemistry and information technology.

In addition to these technical disciplines aspects to be dealt with under social and political sciences have to be taken into account.

Having the above mentioned disciplines in mind, the possible trends in future safeguards could be outlined as follows:

- A stronger networking and combination of different sensor types,
- effectively, a further miniaturization based on nanotechnology,
- portable or mobile application of sensor systems,
- remote monitoring with the possibility of real time and delayed data retrieval,
- improved and more appropriate visualization of safeguards results.

The potential of the mentioned scientific disciplines and technologies have previously been presented and analysed in three INMM-ESARDA workshops which took place in the period 1996 to 2000 [9, 10].

7. Summary

The further improvement of the effficiency and effectiveness of nuclear safeguards continues to require the development of new safeguards systems. Experience from the past as well as future perspectives show that this problem can only be tackled by implementing a comprehensive interdisciplinary research approach. It will be reasonable to perform this research taking into account the requirements from other verification fields such as the Chemical Weapons Convention and the Biological Weapons Convention.

For reasons of sharing the burden, making efficient use of resources and gaining international acceptance it will be necessary both to use national research capacities and to build up research networks on the multinational and international levels. Existing examples are the Member States Programmes in Support of the IAEA, but also the European Safeguards R & D Association (ESARDA) and its cooperation with the US Institute of Nuclear Materials Management (INMM). The positive experience from the INMM-ESARDA workshops should be further pursued in future workshops.

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