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IAEA Department of Safeguards Long-Term R&D Plan, 2012-2023

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1 Purpose and scope

This document presents the Long-Term Research and Development (R&D) Plan of the Department of Safeguards for the 12-year period from 2012 to 2023. The Long-Term R&D Plan is part of a suite of strategic planning documents developed under the departmental long-range strategic planning framework, which also includes the IAEA Department of Safeguards Long-Term Strategic Plan, 2012-2023[1] and the biennial Development & Implementation Support (D&IS) Programme for Nuclear Verification, the current one covering the period 2012-2013[2]. In addition, these long term planning efforts contributed to the preparation of the IAEA Medium Term Strategy, 2012-2017[3].

The Long-Term R&D Plan is designed to support the Long-Term Strategic Plan by setting out the capabilities that the Department of Safeguards needs to achieve its strategic objectives and key milestones towards achieving those capabilities, for which Member State R&D support is needed. The Long-Term R&D Plan covers a wide variety of areas such as safeguards concepts and approaches; detection of undeclared nuclear material and activities; safeguards equipment and communication; information technology, collection, analysis and security; analytical services; new mandates; and training.

2 Strategic planning framework and R&D

2.1 Background

In 2008, the Deputy Director General, Head of the Department of Safeguards, launched the Long-Range Strategic Planning Project. The methodology for long-range strategic planning in the Department of Safeguards was approved for implementation in October 2008. That methodology was then applied to develop the Department's first Long-Term Strategic Plan covering a 12-year period (2012-2023). This Plan was approved for implementation in August 2010. The project provides the Department of Safeguards with a comprehensive and coherent planning framework, covering the long term (Long-Term Strategic Plan – 12 years), the medium term (the Medium Term Strategy – six years) and the short term (the D&IS Programme – two years).

2.2 Long-Term Strategic Plan and R&D

The departmental Long-Term Strategic Plan, 2012-2023 supports internal decision-making on programmatic priorities and allocation of resources, enabling the Department to focus its efforts and resources where they are most needed. The Long-Term Strategic Plan calls for the development of an accompanying R&D plan, covering the same 12-year period, outlining the R&D directions needed to support the Long-Term Strategic Plan. As part of the R&D plan development effort, a workshop titled: *Science & Technology Innovation and the IAEA Department of Safeguards Long-Term R&D,* was held in January 2012. The workshop was intended to ensure that the Long-Term R&D Plan considers scientific and technological innovations in key areas associated with the Department's strategic objectives. It was designed to supplement the Department's knowledge on R&D performed by IAEA Member States and make the Department aware of cutting-edge research occurring outside

[1] A summary of which is available at *http://www.iaea.org/OurWork/SV/Safeguards/documents/LongTerm_Strategic_Plan_(20122023)-Summary.pdf*

[2] *Development and Implementation Support Programme for Nuclear Verification 2012–2013,* (STR-371), IAEA, 2011.

[3] *http://www.iaea.org/About/mts2012_2017.pdf*

the Department's usual interactions on R&D. A summary[4] of the outcomes of the workshop has been produced and the results have been included in the substance of this Long-Term R&D plan.

2.3 The Long-Term R&D Plan and the biennial D&IS Programme for Nuclear Verification

The Long-Term R&D Plan provides an essential step in the hierarchy between the Long-Term Strategic Plan and the biennial D&IS programme. The specification of long-term capabilities needed, with milestones and urgencies, provides a framework to help stakeholders, particularly coordinators of Member State Support Programmes (MSSPs), to decide where their resources can best be used, and also to help the Department formulate the projects that make up the biennial programme and monitor progress towards the strategic objectives.

The biennial D&IS Programme for Nuclear Verification is currently composed of 24 projects. These projects are themselves composed of over 300 sub-projects (known as 'tasks'). Each project contains key objectives, targets and activities that are defined for the relevant two-year period. Both internal tasks carried out by IAEA staff and consultants, and external tasks carried out under MSSPs, are captured in the projects, some of which are aimed at meeting shorter-term needs and others that are part of longer-term R&D efforts.

3 Strategic context

A number of developments are expected to affect the IAEA and its Member States in the future, thereby impacting also the IAEA's nuclear verification mission. They will not only pose challenges but also offer opportunities for the Department of Safeguards.

Concerns over the spread of nuclear weapons remain high due to discovered or suspected cases of non-compliance with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). For some years now, the Department of Safeguards has been carrying out intensive safeguards investigations of special cases discussed in the IAEA Board of Governors. To maintain confidence in nuclear non-proliferation, the international community increasingly relies on the IAEA's safeguards system to deter proliferation through the *early* detection of potential misuse of peaceful nuclear programmes and to provide *credible* assurances of States' compliance with their commitments to use nuclear material and facilities solely for peaceful purposes.

To meet these expectations, the safeguards system must be responsive to changes in the nuclear landscape. In the civilian nuclear sector, there is growing interest in nuclear energy, both for electricity generation and other applications. International nuclear cooperation between States is intensifying – with an expansion of trade in nuclear and related equipment, items and materials. Should the potential nuclear expansion materialize, many additional nuclear activities and facilities would be brought under safeguards. Moreover, sensitive nuclear activities, such as enrichment and reprocessing may become more widespread. At the same time, globalization is aiding proliferation: growing global trade and the erosion of borders makes it easier for nuclear supply networks to covertly supply nuclear and related technology to interested parties and the internet facilitates the uncontrolled spread of sensitive nuclear know-how. In short, demands on IAEA safeguards are growing and becoming more complex. All of this requires the Department to rethink how it can carry out its safeguards activities more effectively and efficiently and invest its resources in areas where they can make the greatest difference in preventing nuclear proliferation.

[4] *Science & Technology Innovation and the IAEA Department of Safeguards Long-Term R&D, 16-20 January 2012, Vienna, Austria, Executive Summary,* (EPR-325), IAEA, 2012.

Besides implementing safeguards, the IAEA may be requested to carry out additional nuclear verification tasks, including those related to nuclear disarmament. The IAEA has already been providing technical expertise to the discussion of a proposed Fissile Material (Cut-off) Treaty (FM(C)T). It is now engaged in negotiating a trilateral agreement related to the verification of the Plutonium Management and Disposition Agreement (PMDA) between the United States of America and the Russian Federation which involves the removal of about 68 tonnes of weapons plutonium from the countries' defence inventories. Also, it may be asked to verify the freezing or dismantlement of nuclear weapons programmes. Thus, the Department will need to be prepared to assist further in these non-traditional verification areas.

Nuclear technology will continue to advance. For example, third generation water-cooled reactors are under construction. Prototypes of fourth generation nuclear energy systems may be ready in the 2020s, with on-line deployment planned for the 2030 to 2040s. New types of power reactors are being developed, including transportable mini-reactors and floating nuclear power plants. Moreover, the first nuclear powered military submarine in a non-nuclear weapon State is planned. New enrichment processes, including new laser and possibly plasma processes, may emerge alongside, or replace, currently deployed commercial enrichment techniques. Pyrochemical processing of spent fuel has been of interest in the last decade. All of this suggests that the Department must prepare to safeguard new, more advanced types of nuclear installations in the future.

The pace of the scientific and technological evolution will offer important opportunities. For instance, computerized devices are evermore capable and innovative technologies, such as artificial intelligence and virtual reality tools, are fast evolving. High-speed digital data networks cover increasingly large portions of the globe. Wireless and satellite communication are more ubiquitous. Information fusion and search tools are ever smarter. Storage capacities continue to increase, making the storage of huge volumes of data possible and less expensive. Such advances have the potential to substantially change the IAEA's technical capabilities and tools.

In all of these areas the IAEA will need the R&D support of its Member States to meet the challenges faced and to take advantage of the opportunities offered.

4 Strategic objectives

The Department of Safeguards' three over-arching strategic objectives are to:

Deter the proliferation of nuclear weapons, by detecting early the misuse of nuclear material or technology, and by providing credible assurances that States are honouring their safeguards obligations;

Contribute to nuclear arms control and disarmament, by responding to requests for verification and other technical assistance associated with related agreements and arrangements; and

Continually improve and optimize departmental operations and capabilities to effectively carry out the IAEA's verification mission.

The Department pursues these objectives within the mandates provided by the IAEA Statute[5] and the safeguards agreements that States have concluded with the IAEA: comprehensive safeguards agreements with non-nuclear weapon States based on INFCIRC/153 (Corrected); voluntary offer safeguards agreements with the five nuclear weapon States party to the NPT; item-specific safeguards

[5] *www.iaea.org/About/statute.html*

agreements based on INFCIRC/66/Rev.2; as well as protocols additional to any of the above safeguards agreements, based on INFCIRC/540 (Corrected).

5 R&D to achieve strategic objectives

The Department has set out in the following table the long-term capabilities that it needs in order to meet its strategic objectives. These are technical capabilities for which Member State R&D support is or may be needed. These capabilities cover a wide area, including:

- Concepts and approaches;
- Detection of undeclared nuclear material and activities;
- Safeguards equipment and communication;
- Information technology, collection, analysis and security;
- Analytical services;
- New mandates; and
- Training.

Each capability is then broken down into more detailed key milestones, the completion of which will contribute to the full realization of the capability. The perceived urgency for each milestone is defined as high, medium and low. This describes the immediacy of the need and should not be confused with 'importance' as all of the milestones are important to meeting the strategic objectives. The urgency reflects the timeframe in which the milestone needs to be met, or development efforts need to begin, to meet the milestone in the long term.

In many of the areas detailed in the table, the Department already has a certain level of capability, but in all of them that capability needs to be increased to ensure that the IAEA can continue to draw soundly-based safeguards conclusions, that the IAEA's resources can be most effectively utilized and that future challenges can be met.

6 Review and update of the plan

As detailed in the Long-Term Strategic Plan, the suite of strategic planning documents is reviewed periodically, ranging from two years for the Development & Implementation Support (D&IS) Programme for Nuclear Verification, to six years for the Long-Term Strategic Plan. The Long-Term R&D Plan will also be formally reviewed and an updated plan released every six years, with interim biennial reviews. The milestones detailed in the Long-Term R&D Plan will be used to monitor progress.

7 Table of capabilities, milestones and urgencies

Long Term Capabilities Needed	Milestones	Urgency
1. Ability to fully implement the State-level concept for the planning, conduct and evaluation of safeguards.	1.1 Develop safeguards policy, guidelines and processes to more fully implement the State-level concept.	H
	1.2 Prepare additional guidance for the ongoing development of State-level safeguards approaches: • The use of State-specific factors • Acquisition path analysis • The specification of options for Headquarters and in-field activities required to meet the technical objectives • The link between the State evaluation process and development of SLAs[6] and AIPs[7]	H
	1.3 Develop additional tools to support the development of State-level safeguards approaches: • The analysis, representation, and prioritization of acquisition paths • The planning of safeguards activities • The assessment of overall safeguards effectiveness • The determination of technical objectives	M
	1.4 Develop approaches to more fully utilize SRA[8] data and verification findings, where appropriate, to achieve efficiencies.	H
	1.5 Develop safeguards guidance for States, including web-based versions, addressing topics such as: • Regulatory authority • Design information • Inspections and complementary access • Imports and exports	M
2. Increased ability to detect undeclared nuclear material and activities.	2.1 Integrate information sources, including satellite imagery, electronic data (including images), technical and academic literature, trade data, etc., to detect inconsistences in nuclear programmes and States' declarations.	M
	2.2 Develop elemental and isotopic signatures of nuclear fuel cycle activities and processes (e.g. uranium conversion and laser enrichment), and apply them to analysis of environmental sampling and destructive analysis of nuclear material using mathematical, statistical and graphical tools.	H
	2.3 Develop analytical methodologies, tools, and techniques for 'all source analysis', including the update of the 'Physical Model', to detect signatures of	M

[6] State-level approaches
[7] Annual implementation plans
[8] State/Regional Authority

	undeclared activity, and improve analysis of nuclear fuel cycles, including weaponization.	
	2.4 Evaluate data analysis methods and computerized tools to aid the analysis of the large amount of all-source information in order to support the State evaluation process and assist in drawing soundly-based safeguards conclusions.	M
	2.5 Develop statistical methodologies and mathematically based approaches to optimize safeguards verification approaches and evaluation of results.	M
	2.6 Develop instruments and associated techniques to detect the establishment and operation of nuclear fuel cycle activities, for example by detecting process emanations.	H
3. Ability to safeguard new types of facility.	3.1 Develop generic safeguards approaches for: • Pyroprocessing plants • Other new reprocessing technologies • Laser enrichment plants • Other new enrichment technologies • Small modular and/or Gen IV reactors	 M L M L M
	3.2 Develop tools and techniques to characterize: • Fissile content in metal mixtures containing the actinides Np, Am and Cm during pyroprocessing • Fuel types for Gen IV reactors containing minor actinides • Seismic signals in geological repositories	 M L M
	3.3 Develop training to reflect the approaches and equipment for safeguarding new types of facility, including consulting with States developing such facilities to help assess what training is required.	L
	3.4 Develop a mechanism to enable safeguards to be considered early in the facility design process.	M
4. Ability to provide credible assurances that nuclear material used in non-proscribed military activities, specifically naval propulsion, is not used for the production of nuclear weapons or other nuclear explosive devices.	4.1. Consult with Member States with established naval nuclear propulsion programmes for development of future verification arrangements in this area.	H
	4.2 Develop concepts, tools, and measures to enable the IAEA to design a verification approach for nuclear material destined for, and returned from, naval propulsion	M
	4.3 Develop an approach to provide credible assurance that nuclear material being used in naval propulsion is not used for the production of nuclear weapons or other nuclear explosive devices.	M
5. Ability to deploy equipment at facilities to meet safeguards requirements.	5.1 Develop improved tools and techniques to detect misuse of reprocessing plants (real time detection of Pu separation)	L
	5.2 Develop tools and techniques to enable timely, potentially real time, detection of HEU production in	H

	LEU enrichment facilities.	
	5.3 Develop improved tools and techniques to enable real time flow measurements of nuclear material, including UF_6 at enrichment facilities and Pu at reprocessing facilities.	M
	5.4 Develop appropriate safeguards equipment to establish and maintain knowledge of spent fuel in shielding/storage/transport containers at all points in their life cycle.	M
	5.5 Develop methods to verify fresh fuel in shipping containers without opening the containers.	M
	5.6 Develop improved NDA instruments and techniques to address verification of waste and scrap nuclear material with impure composition or heterogeneous isotopic composition.	M
	5.7 Develop more sensitive and less intrusive alternatives to existing NDA instruments to perform partial defect test on spent fuel assembly prior to transfer to difficult to access storage.	H
	5.8 Develop alternative NDA instruments, for instance based on liquid scintillators, to improve performance in neutron coincidence counting techniques applied to various types of fissile material.	M
6. Ability to acquire and deploy safeguards equipment that is sustainable, standardized and modular, with increased use of commercial off-the-shelf products.	6.1 Implement an improved cost/benefit assessment methodology for the design and operation of safeguards equipment.	M
	6.2 Develop neutron counting systems reducing the use of ^3He or offering equivalent functional and technical alternatives.	M
7. Ability to make maximum efficiency savings by the use of remote monitoring of operators' and unattended IAEA equipment.	7.1 Develop minimally intrusive techniques that are both secure and authenticated to enable the use of operator's systems, instruments and process monitoring for cost effective safeguards implementation.	H
	7.2 Conduct improved intrusiveness and vulnerability analysis on current and future use of unattended systems, particularly to address any new threats resulting from technology advancements.	M
8. Ability to use safeguards information in a fully integrated, secure environment, maintained and available to all who need it according to their role.	8.1 Develop a fully integrated, secure safeguards data environment (ISE), including all State reports under a safeguards agreement and declarations under an additional protocol, and an electronic State file containing all safeguards-relevant information about each State.	H
	8.2 Create links between exemptions and terminations of nuclear material with the nuclear material accounting database to allow automatic checking of State reporting.	H

9. Ability to communicate secure, authentic information that is fully compatible with ISE between the IAEA, SRAs and inspectors/equipment in the field.	9.1 Develop updated software tools for use by SRAs in creating and submitting accountancy reports and additional protocol declarations, supporting the further integration of State declared information within the electronic State file.	M
	9.2 Deploy secure and authenticated communications between the IAEA and SRAs.	M
	9.3 Deploy secure and authenticated communications between inspectors in the field and IAEA headquarters/regional offices.	M
	9.4 Ensure the Department's ability to recover from an IT failure.	H
10. Ability to provide analytical services through the NWAL[9] to support verification requirements.	10.1 Utilise the expanded NWAL[9], in order to: • Provide external quality control and reference materials • Provide technical expertise	H
	10.2 Develop techniques, methods and equipment to detect signatures of nuclear activities in environmental samples including: • Age determination of U and Pu relevant to the origin of nuclear materials • Analysis of impurities relevant to the origin of source materials • Particles morphology for identifying operational processes • Reliably finding smaller particles of interest in an excess of background material	H
	10.3 Develop and implement techniques for determination of new chemical and physical attributes for strengthening safeguards verification using nuclear material samples. Improve capability to characterize nuclear material and verify its origin e.g.: • Age determination • U speciation • Analysis of U impurities	H
11. Ability to deal with new mandates.	11.1 Develop options and approaches for possible future mandates as required or requested (e.g. fissile material cut off treaty, arms control) that respect sensitive and proprietary information.	L
12. Ability to take on technical challenges and opportunities, and emerging tasks.	12.1 Assist with Chernobyl, Fukushima and DPRK related activities as requested.	M
	12.2 Develop and implement a technology foresight horizon scanning process for external, potentially relevant R&D fields.	M

[9] Network of Analytical Laboratories, which includes the Safeguards Analytical Laboratories.

13. Ability to deploy the required expertise and skills to continue to fulfil the IAEA's mandate(s).	13.1 Develop training tools using advanced methods such as virtual reality, immersive learning systems and web-based training: • Develop prototype virtual reality systems, test and evaluate performance • Include immersive learning for all types of fuel cycle facilities • Develop web-based tools for specific safeguards equipment • Develop signal (neutron/gamma) simulators to generate responses from equipment during training	M
	13.2 Develop training material and remote delivery methods to support SRA training with reduced costs and increased accessibility.	M