ISSN 1977-5296

ESARDA

European Safeguards Research and Development Association

Bulletin

Nº 45

December 2010

ISSN 1977-5296

Number 45
December 2010

ESARDA is an association formed to advance and harmonize research and development for safeguards. The Parties to the association are:
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Scientific and technical papers submitted for publication are reviewed by the Editorial Committee.

Manuscripts are to be sent to the Editor following the 'instructions for authors' available on the 'Bulletin' page of the ESARDA website. Photos or diagrams should be of high quality.

Accepted manuscripts are published free of charge.

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ESARDA Bulletin is published jointly by ESARDA and the Joint Research Centre of the European Commission.
It is distributed free of charge.

The publication is authorized by ESARDA.

Cover designed by
N. Bähr
EC, JRC, Ispra, Italy

Printed by
IMPRIMERIE CENTRALE – Luxembourg

ESARDA
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A Personal Appraisal of 2010...

B. Pellaud

A number of significant events took place in 2010: in May, the Review Conference of the Treaty of Non-Proliferation (NPT) in New York; in April, the Security Summit in Washington; in Summer, the collapse of the Conference on Disarmament in Geneva; and in November, the Safeguards Symposium in Vienna. In all interested circles, these events were accompanied by endless analyses of the political, legal and technical nature of the numerous efforts of the international community to come to grip with the threats associated with nuclear weapons. This scrutiny is of good omen, but there is too frequently the tendency to bypass some plain facts for fear of breaching diplomatic or bureaucratic conventions. Yet, there are significant things to recognize – in order to truly understand the progresses and the failures of the broader non-proliferation agenda.

The NPT Review Conference

The NPT Review Conference concluded on 28 May with the adoption of a final document. This was a noteworthy achievement in comparison with 2005, a meeting that ended in rancour and without a concluding document. The 2010 document contains a number of useful statements about disarmament (a support for the launching of FMCT negotiations), about the detailed implementation of the treaty, and a solid endorsement of the IAEA. Nonetheless, it failed to say anything substantial about several important issues, such as 1) the withdrawal from the Treaty as per Article X (remember that in 2003, North Korea stepped out in a state of non-compliance without the Security Council taking much notice), 2) the universal adoption of the Additional Protocol (*"adoption encouraged"*, but not declared a NORM for all in the NPT framework), and 3) the drive towards multilateral, or rather "non-one-nation" expansion of sensitive nuclear technologies (an approach that does not curtail essential rights under Article IV).

The NPT Conference was dominated by the bilateral feud between the United States and Egypt, the latter claiming to speak on behalf of the Non-Aligned Movement (NAM). In order to make a final document possible at all, the United States watered down the contents to too low a level and in addition endorsed the holding of a Middle East conference focused on Israel in 2012, a propaganda undertaking of the Muslim countries that will lead nowhere, since Israel will not attend. To be credible, the NAM should have set their sight higher, at the discriminating nature of the NPT itself, by calling a conference to address the status of ALL non-NPT States – Israel, India and Pakistan. In essence, whereas the US, Europe and others were attempting to strengthen the non-proliferation regime, Egypt and the NAM were just playing elusive regional political games.

Broadly speaking, New York was just the tip of the iceberg, the most recent one. For many years, the IAEA has been the stage of a major struggle between the "developed" and the "developing" worlds, the first eager to tighten the non-proliferation regime through more intrusive safeguards inspections, the second willing to go along only partially and only in exchange, firstly, of more technical assistance in nuclear technology, a legitimate objective, and, secondly, of a more lenient handling of NAM individual members found in violation of their NPT commitments. How to reach more common views and ensure a more rational decision-making process at the IAEA Board of Governors? On the one side, the West should stop taking high-handed, sometimes even imperialistic decisions on proliferation issues, that is, fundamental issues that would call for more prior consensus. A first example was the futile attempt of the Bush Administration to divide the world into two groups, those with and those without a fuel cycle; a second example was the politically damaging US-India agreement (damaging in the NPT context since in blatant violation of past practice), an agreement concluded without prior consultations and imposed by downright threats and blackmail on dissenting members of the Nuclear Suppliers Group; a third example has been the mistaken attempt to deny Iran the right to enrich at all, instead of focusing on Iran's serious violations of its safeguards agreement. On the other side, the developing world should hopefully grow beyond petty regional politics and understand the global importance of non-proliferation. The Arab States in particular should focus less on Israel, and help more in bringing about a settlement of the Iranian nuclear issue, since a nuclear-armed Iran could turn out to be a greater challenge to the Arab status and security in the Middle East than Israel's nuclear arsenal.

The Nuclear Security Summit

The Nuclear Security Summit held in Washington just prior to the NPT Conference was assuredly a puzzle. Why did President Obama convene 36 innocent heads of States to discourse about nuclear security? Was it to draw attention of these guests to the forthcoming NPT Conference? Was it a genuine concern about nuclear material security? During the media buzz that preceded the Summit, President Obama painted the devil on the wall, warning of nuclear weapons or bomb-grade nuclear materials being stolen and falling in the hands of terrorists. The coolest response to these horror, warming-up scenarios came from the President of Switzerland, Mrs. Doris Leuthard, who stated publicly in Washington during the Summit: *"If this is the case, then nuclear weapons States should get together urgently and solve their own problems; there is no reason for us, security-abiding non-nuclear weapons States, to be here in Washington".* The final document of the summit contains a number of rubbery generalities and also some specifics not much different from the conclusions of the March 2009 IAEA Symposium on Nuclear Security, which I had the honour to preside. Evidently, the proposed follow-up summit meeting of 2012 in Seoul makes little sense; it should be limited to weapons States. Meanwhile, real international work should continue through security specialists meeting in Vienna, set to resolve the nitty-gritty of the security field in the absence of politicians. The politicians are only asked to ensure domestic implementation of the findings. Everything else is political posturing.

FMCT and the Conference on Disarmament

The failure of the Conference on Disarmament (CD) to launch negotiations on a Fissile Material Cut-off Treaty was the major non-event of the year. After the adoption of a tentative programme of work in 2009, there was genuine hope that the FMCT would finally take off. Informal sessions took place in June 2010, during which I was asked to present a substantial paper on technical issues and negotiation modalities of a FMCT on behalf of the Swiss Delegation. The discussion revealed a high level of awareness and readiness to move ahead on the part of almost all diplomats present in the room at the United Nations in Geneva. To no avail. The rules of the 65-State CD require unanimity on all decisions, with collective decision-making going as far as commas and periods. The stumbling block: Pakistan, which wants no FMCT, claiming that such a treaty would weaken its national security. Not satisfied with the option of ignoring such a treaty once negotiated, Pakistan wants to prevent others – all nuclear-weapons States – to even negotiate an FMCT! In a sense, Pakistan engages in the similar logic as used previously to undermine the NPT: not joining the treaty (a fundamental right), developing nuclear weapons (a legitimate right resulting from the previous) and subsequently selling the weapon technology around the world for hard currency, a criminal activity that was never condemned by the Security Council (and only tepidly by most governments). As a matter of fact, Pakistan's felonious activities are the real and only reasons for the perceived and much debated "weakening of the NPT". Also staggering in Geneva is the soft support enjoyed by Pakistan from NAM's prominent members. Broadly speaking, it is disturbing to see the NAM shields Pakistan in Geneva in its attempt to block the FMCT and shields Iran (and Pakistan) in Vienna when the IAEA tries to resolve NPT safeguards violations. Yet, some of the same NAM countries are those most vocal against the US and other weapons States – which are relentlessly accused of not doing enough in the direction of nuclear disarmament! Subsequently, on 24 September, the UN Secretary General convened a special meeting in New York to discuss the paralysis of the CD. Under pressure from the NAM, the published document failed to make any clear-cut proposal for the resolution of the crisis, that is, either moving the FMCT negotiations from the CD agenda to the UN agenda (as done with the Comprehensive Test Ban Treaty in 1996 when negotiations got bogged down at the CD), or more appropriately the dissolution and the reconstitution of the CD with fewer members and without the unanimity rule.

The IAEA Safeguards Symposium

Last, but not least, the November IAEA Safeguards Symposium. Held about every four years, this is the opportunity to review all aspects of safeguards implementation by the IAEA inspectorate. The new Deputy Director General, Herman Nackaerts, painted a forward-looking and dynamic perspective of the safeguards system: *"That is why we need to move further away from an approach that is narrow, prescriptive, criteria-driven, and focused at the facility level – to one that is more objectives-driven, customized, and focused at the State level. This makes sense because we need to be guided by objectives rather than procedures: concerned with outcomes rather than process…Today, I have made clear our determination to accelerate the Agency's move towards a Safeguards system that is fully driven by the use of all the safeguards-relevant information available to us."* This is a refreshing and welcome vision.

Through collaboration with organisations like ESARDA and the national support programmes, the IAEA continues to develop new technologies in order to improve the **effectiveness** of the safeguards system. Besides new technology, improved concepts and methods are in fact necessary to modernise and streamline the safeguards system to ascertain that inspection resources are used with **efficiency** and – also – without **excessive data acquisition** in facilities and in States under safeguards. Those are three objectives that are of prime importance. The first criterion gets most of the attention, the second is taken into account whenever possible, be it only as a means to overcome budgetary constraints; the third may slowly gain in importance for the States under safeguards.

The new world of safeguards began in 1995 with the adoption of new technologies, in particular, satellite imagery and environmental sampling. With the introduction of the Additional Protocol in 1997, the opportunity emerged to develop a new rationale for IAEA Safeguards implementation, evaluation and the distribution of safeguards effort. Article 4 stipulates that *"The Agency shall not mechanistically or systematically seek to verify the information referred to … in the Additional Protocol".* The "Old System" was mainly related to quantity and quality of nuclear material and facilities. The development of safeguards criteria had in the past led to a mechanistic checklist system – with attainment goals for material quantity and timeliness as performance factors. Once the Additional Protocol had been adopted by more and more countries, there was the risk of a bureaucratic approach to the additional Protocol, an approach reminiscent of the old system. Under the flag of Integrated Safeguards, the Agency did make an attempt over the last decade to better bring together effectiveness and efficiency, but did so again within too rigid a corset of detailed quantitative rules and guidelines.

When Mohammed ElBaradei (as head of the legal/political team) and I (as head of the Department of Safeguards) brought the Additional Protocol to the IAEA Board of Governors for final approval in the midnineties, we did promise that this legal instrument would be applied *not mechanistically or systematically*, and that its potent tools would be used on a customised basis so as to enhance the inspectorate's work in special circumstances, and not systematically across the board and across the world. Today, the new approach defined by Herman Nackaerts does reflect in a more sophisticated framework the original spirit of the Additional Protocol. To quote him: *"We need to further develop our conceptual approach to safeguards implementation: an approach that makes better use of all information available to the Agency in defining State-specific approaches and associated verification activities."* Yet, clarification and caution are still needed.

At the November Safeguards symposium, a new terminology seems to have been adopted, that of "an *information-driven safeguards system*". What does that mean? Some have said a system based on flexible and objective factors; others, a customised State-level approach using State-specific factors. Good. But many keen observers of the safeguards scene have not much sympathy for the expression "information-driven", because it's too restrictive and because it could become the cover for an ever-more uncurtailed collection of information. In Vienna, we heard about having full satellite imagery and environmental samples in the vicinity of all nuclear facilities of the world. And an interest in monitoring electronic mail on internet social networks and in a "Digital Continuous State Evaluation"! The last speaker painted the outline of what can be labelled a "fully automated information-saturated digital safeguards system" – one presumes even without inspectors! Cool heads are needed to keep sight of the basic safeguards objective! Information is a tool, not an objective. Instead of "information-driven", I would therefore suggest adopting the expression **"factors-driven safeguards system",** because the word "factor" is general and flexible; it's *"constituent, ingredient, element, part, particular, piece, component; circumstance, consideration, aspect, fact, influence, determinant, cause"* (Oxford Thesaurus). The word "factor" is broad enough to cover many other things of relevance to safeguards, even intentions and physical indicators.

In a sense, the wish or the need to seek more and more information may be justified by the now standard, but unfortunate formulation *"…the IAEA is to provide credible assurances about the non-diversion of declared nuclear materials and **about the absence of undeclared activities**".* The Symposium participants were told that BOTH conclusions were drawn with a "high level" of assurance. This is not very credible: if a few measurements can take care of the first conclusion in a country like Switzerland, how many environmental samples would be needed for the second? One million, as suggested by the Director of Technical Support at the IAEA, Sergey Zykov? Of course a few correlative and plausibility factors would suffice in practice; yet some safeguards analysts would welcome all these samples to feel fully at ease in an information-driven system.

In this evolution, my special concern is about **excessive data acquisition.** Clearly, the IAEA should receive and should seek the information that it needs to perform its activities, differentiating among States, as appropriate. Out of habit, or to escape accusation of discrimination among States, the system could ultimately drift towards a system of comprehensive data collection across the world, towards the build-up of unlimited data inventories beyond effective needs, as noted above. There is a risk of going too far. In my view, this issue of confidentiality at the international level corresponds to the red line that requires consideration at the local and national level. To fight criminality effectively, police does needs street cameras, wire-tapping and other monitoring of a number of citizens. But not: cameras in all living quarters and wire-tapping of all citizens. In democratic countries, there are official government agencies and private associations to check police abuses and Google's illegal collection of data from the street. In case of abuses, the issue of "privacy of the citizen" could grow up into an issue of "privacy of the country", if international organisations would go too far in the acquisition and in the accumulation of excessive data.

The Safeguards Symposium 2010 was a milestone in the evolution of safeguards. It brought to light very significant technological developments in all areas of importance to the IAEA inspection system. More significant, it demonstrated the capability of the Department of Safeguards to redefine its own mission through a better balancing and integration of its inspection rights under the conventional safeguards system and the now mature legal environment of the Additional Protocol.

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ESARDA News

Safeguards in Poland after Joining the Multilateral Agreement with the IAEA and EURATOM

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Abstract

The paper presents the activity of the Division for the Non-Proliferation in the NAEA of Poland in the field of Safeguards after joining the multilateral Agreement between the EUs non-nuclear weapon states, Euratom and the IAEA. The structure of the system, legislation, inspection activities, used software, types of accountancy and Additional Protocol declarations are described. Practical difficulties in transformation to EURATOM Safeguards are characterised.

Keywords: safeguards; integration; EURATOM.

1. Introduction

Poland, is a party of the Treaty on the Non-Proliferation of Nuclear Weapons from its beginning. The Treaty was signed on the July 1st 1968 and ratified on June 16th 1969. Poland has concluded the Agreement with the International Atomic Energy Agency for the application of Safeguards, based on the IAEA INFCIRC/153. This Agreement entered into force on October 11th 1972. Since then safeguards has been applied on all direct and indirect use nuclear material within the territory of Poland.

In May 2000 Poland ratified the Additional Protocol to the Agreement on Safeguards between Poland and the IAEA.

In May 2004, Poland joined the European Union and the Euratom Treaty entered into force in Poland.

The IAEA scheme of Integrated Safeguards was introduced in Poland on March 1st 2006.

On March 1st 2007 Poland joined the multilateral Agreement with the IAEA and EURATOM and the Additional Protocol to this Agreement – INFCIRC/193 Add. 8.

2. Polish jurisdiction in the field of Nuclear Material Accountancy and Control

Despite the international agreements, the dual use goods list described in the Regulation of the Council of European Union no 428/2009 and the Commission Regulation no 302/2005 on the application of Euratom safeguards are the basis for the application of safeguards in Poland. Other national regulations are the following:

- "Atomic Law" – Act of Parliament of November 29th 2000 – in force since 1.01.2002,
- Law on export and import control of strategic goods and dual use items, the Act of Parliament of November 29th 2000,
- Regulations of the Council of Ministries of October 4th 2008 on Physical Protection of Nuclear Material and Nuclear Facilities.

These regulations will be updated in the near future due to the national programme of use of nuclear energy in electric power generation.

3. System for Nuclear Material Accounting for and Control in Poland

Nuclear material accountancy and control as well as physical protection of nuclear material are under supervision of the National Atomic Energy Agency (NAEA) based on national legislation. Nuclear material control is performed by state inspectors from the Non-Proliferation Division of the Department of Radiation and Nuclear Safety. Like in other EU countries the operators of nuclear facilities and nuclear material holders are responsible for the accountancy of nuclear material in their possession. The European Commission and the NAEA is responsible for implementation of the Safeguards Agreement and its Additional Protocol. NAEA is the coordinating and central accountancy body reporting to the Commission for nuclear material accountancy in material balance areas (MBA) of small holders. Poland has the following MBAs:

1. Research reactor MARIA (designed for 30 MW) and research laboratories of the Institute of Atomic Energy POLATOM (IEA POLATOM). IEA is the Scientific Institute and the operator of this research reactor. The main characteristics of the reactor are the following: reactor started in 1975, fuel type MR-6 enriched now to 36%, fuel construction – six coaxial aluminium pipes with uranium aluminium alloy, licensed power up to 1,8 MW per fuel channel, thermal neutrons flux up to $1{,}5 \cdot 10^{14}$ n/s*cm^2, due to the presence of beryllium matrix in the core there is more space between elements for neutron channels, the reflector is made of graphite blocks.

2. Waste Management Plant which was also responsible for spent fuel from research reactor EWA (10 MW) which was decommissioned after almost 40 years of operation in 1999, the spent fuel was sent this year to Russia.
3. Research laboratories of the Institute of Nuclear Studies.
4. Centre for Radioisotopes POLATOM which is now a part of the IEA POLATOM.

   All the above mentioned organizations are located in Świerk near Warsaw.
5. Institute of Nuclear Chemistry and Technology located in Warsaw.
6. Small holders at approximately 120 locations (small quantities of nuclear material in industry, high schools, scientific institutes, laboratories and in hospitals).

Another MBA was created for material in small holders which will be derogated under Regulation 302/2005 and exempted under articles 37 (shielding material, non in nuclear use) and 36(b) (measuring devices) of the Agreement.

The Division of the Non-Proliferation in NAEA is responsible for collecting and maintenance of all accountancy data and other information relevant to nuclear material balance and movements between MBAs and from/to the country for national purposes. This documentation is based on the copies of declarations send to the EURATOM Safeguard Office in Luxembourg (Directorate Nuclear safeguards of Directorate General for Energy of the European Commission) as well as on documents received during inspections performed by the state inspectors from NAEA.

There are two persons involved in the work of the Division. One of the inspector is the head of the Division and the second one is the operator of the computer accountancy database system and archives.

The responsibility of the national office covers the following:

- maintenance of the accountancy records and reports for the MBAs,
- safeguards inspection and control of nuclear material and performing of nuclear material assay if necessary,
- participation in the inspections and other activities performed by the IAEA and EURATOM inspectors,
- export/import control of nuclear material and other dual use items,
- issuing opinions on licence requirements regarding export/import control,
- expertise required for international coope-ration in the area of safeguards and other related matters,
- expert advice for operational procedures used in the accountancy of nuclear material.

4. Inspection activities

State Inspection activities concentrate on:

- control of the presence of nuclear material and verification of the completeness and correctness of the nuclear material accountancy documents at the nuclear facilities and other users of nuclear material,
- ordering the measurements of nuclear material enrichment (NDA) and quantity (NDA, weighting) if necessary,
- control if the nuclear material user meets the requirements and principles of nuclear material safeguards according to the approved nuclear materials accounting and control system of a facility or small holder.

There are 4 types of safeguards inspections performed by the state inspectors together with the IAEA and EURATOM inspectors:

- unannounced inspections under called Integrated Safeguards,
- routine inspection to control the nuclear material balance and correctness of the safeguards accountancy data in comparison to the reports received by national office,
- "ad hoc" inspections – to control the data which can not be verified on the basis of the received reports and to control if the recommendations issued during previous inspections are met,
- special visits which may be performed e.g. according to the requirements of the Additional Protocol.

NAEA safeguards inspectors perform also inspection without the participation of international organisations in the field of nuclear material accountancy and export/import control.

The common Euratom/IAEA inspections at the research reactor are performed routinely on a monthly basis (due to amount if fresh HEU present at this installation) and include one PIV/year. Other Material Balance Areas are inspected at least once per year after physical inventory taking.

In addition to the PIV and verification of the accountancy data, the following measures are being applied by the EURATOM and the IAEA inspectors:

- common COBRA seals on the fresh fuel,
- paper seals on the storage areas and containers,
- transport containers sealing,
- measurements with NDA-methods,
- advanced thermal reactor power monitoring.

5. Nuclear Material under Safeguards in Poland

Safeguards is being applied in Poland according to the provisions of the Agreement with the IAEA and EURATOM on:

- special fissionable material (Pu-239 and enriched uranium),

- source nuclear material
- natural and depleted uranium and thorium.

The total amount of nuclear material in Poland in 2009 was less than 19 SQs. After sending of all spent fuel to the Russian Federation in 2010 this amount is decreased by about 90%. Shipments of the spent fuel were transported by train to a sea port and by ship to Russia.

Nuclear material in Poland is used mainly at the research reactor which is operating for research, training, isotope production purposes and other commericial activities. Nuclear material used at the research reactor are mainly highly enriched uranium fuel. The fuel elements are accounted for based on shipper certificates data. Each fuel element has its own certificate and engraved identification number. Spent fuel is stored at the reactor site in water pools. The enrichment of fuel in use is now 36% but in the future will be decreased to less than 20%.

In location outside facilities small quantities of uranium, thorium compounds and plutonium (Pu-Be neutron sources) are used for research and industry. Depleted uranium is used mainly as shielding for highly radioactive gamma sources used in industry.

6. Used software

Due to small experience of users for nuclear materials reporting the EURATOM ENMASLight software is used. Other software is used for accountancy database management by operators in MBAs.

For preparing Additional Protocol declarations at the Division for the Non-Proliferation the IAEA Protocol Reporter is used.

7. Integrated Safeguards

After introduction of the IAEA scheme of Integrated Safeguards rules the number of inspections decreased because quarterly inspections of spent fuel in two facilities discontinued. Instead of that there is a small number of unannounced inspection in these facilities. Inspectors arrive at the gate to the institute and inform the operator on an unannounced inspection. The fax is sent to the NAEA. A state inspector from the NAEA is arriving with a small delay at the facility and is participating in the inspection. Due to the distance and no advance information to the Commission the EURATOM inspectors do not participate in such an inspection. The inspection program of inspection is similar to the routine inspections. Updated documents and General Ledger are submitted by the operator to the Commission and the IAEA after inspection. If for example the responsible person at the facility for example is on holidays the facility operator will organize car transportation of that person to the facility.

8. Practical difficulties

The main source of problems during transformation to EURATOM Safeguards were the following:

1. Change of the structure of the material balance areas.
2. Change of format, units, frequency and rules of nuclear material reporting.
3. Small experience in nuclear material reporting of the accountancy officers at the facilities.
4. No full information flow during transformation.

The New Safeguards R & D Structure in Germany - Coordinating the German Support Programme to the IAEA

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In 1978, the International Atomic Energy Agency (IAEA) and the German Government, then represented by the Federal Ministry of Research and Technology, agreed upon the "Joint Programme on the Technical Development and Further Improvement of IAEA Safeguards". From the very beginning, an essential part of the programme was the close involvement of the Euratom Safeguards Directorate. The then Karlsruhe Nuclear Research Centre was in charge of coordinating the programme. Up till now, the programme comprised more than 150 tasks, providing research and development, training of IAEA staff, consultancy support, and the delegation of 17 cost-free experts to the IAEA. The R&D support covers a wide variety of issues such as measurement methods and techniques, safeguards data and information processing, containment and surveillance techniques, safeguards approaches and concepts for future technologies. Since summer 1985, the Jülich Research Centre (Forschungszentrum Jülich, FZJ) has coordinated the programme implementation in close cooperation with the German Government, now represented by the Federal Ministry of Economics and Technology (BMWi). In May 2009, the Institute of Energy and Climate Research, IEK-6: Safety Research and Reactor Technology took over the responsibility for the German Support Programme coordination within FZJ including safeguards research and development.

IEK-6 is part of the Institute of Energy and Climate Research (IEK) at FZJ. IEK was founded very recently in order to focus on solutions for a sustainable energy supply in the future. Besides research on the chemistry and dynamic of the atmosphere, modern energy conversion technologies are being investigated, ranging from photovoltaic and fuel cells to nuclear fusion and nuclear safety research, and innovative coal and gas power plants. Nuclear research, however, has a long tradition at FZJ, which initially started as a nuclear research centre.

IEK-6 focuses on the development and operation of safe, reliable and sustainable nuclear energy systems, and the management of radioactive waste. The institute employs a staff of 85 persons and is structured into the divisions "nuclear waste management" (Heads: Prof. Bosbach, Prof. Thomauske) and "reactor safety" (Prof. Allelein).

IEK-6 is strongly connected with RWTH Aachen University through the Juelich Aachen Research Alliance (JARA) – Energy, with Prof. Bosbach being recently appointed the new JARA-Energy director. Each of the three heads of IEK-6 also holds a chair at RWTH Aachen University; together they developed a new **master programme on Nuclear Safety Engineering** starting at RWTH Aachen in winter term 2010/11. Moreover, IEK-6 cooperates with the Karlsruhe Institute of Technology (KIT) and Forschungszentrum Dresden-Rossendorf (FZD) within the Nuclear Safety Research Programme of the Helmholtz Association (HGF), and many other national and international partners. In the following, the divisions will be introduced in more detail.

Nuclear waste management includes all areas from the production of waste through conditioning and interim storage to the final disposal of the different types of radioactive waste. IEK-6 focuses, in particular, on material science aspects of nuclear waste management.

Basic science is being carried out on long-term safety of geological repositories and innovative waste management strategies:

- The studies on the long-term safety have concentrated, since decades, on the behaviour of spent fuel and high-radioactive waste glass. However, some essential details on the migration and mobilisation of long-lived radionuclides still cause uncertainties in the long-term safety analysis of final repositories. The current research activities focus on nuclear and radiochemical aspects of the near field (waste matrix, technical and geotechnical barriers) in order to gain a profound system and process understanding on the molecular level and thereby contribute to the safety case.
- As alternative to the final disposal of long-lived radionuclides, innovative waste management strategies are being investigated. IEK-6 develops methods for reducing the radiotoxicity of nuclear waste by partitioning (P) of long-lived radionuclides from radioactive waste, their transmutation (T) into short-lived or stable products by neutron irradiation in accelerator-driven systems (ADS) and their selective conditioning (C) in matrices with long-term stability. Furthermore, tailored ceramics are being developed for embedding actinides and long-lived fission products within the two disposal options P&C and P&T.

Applied science includes three different areas besides nuclear safeguards: Characterisation of waste packages, product quality control, and management of nuclear graphite:

- IEK-6 has a long-lasting tradition in developing non-destructive procedures for the characterisation of radioactive waste packages. Methods were developed in close cooperation with the Federal Office for Radiation Protection (BfS) and, today, are being used nation-wide for waste characterisation. Future activities are related with measurement techniques for routine analysis of chemo-toxic waste components, such as the heavy metals lead, mercury, and cadmium. One method being currently established is based on Prompt Gamma Neutron Activation Analysis (PGNAA).
- In this context, IEK-6 includes the Product Quality Control Office for Radioactive Waste (PKS) since 1985. PKS advises and supports BfS in its sovereign and safety-relevant duties by verifying the required quality and safety of nuclear waste prior to transportation to a German final repository. PKS is organized two-fold: PKS-WAA authorized by BfS for the quality control of high- and medium-active nuclear waste from reprocessing facilities, and PKS-I providing experts for BfS in the field of low- and medium-active waste from German nuclear power plants, research institutions and collecting depots of the federal states.
- Moreover, waste management options for irradiated graphite from decommissioned graphite-moderated reactors are being studied. IEK-6 coordinates the European FP7 Project "Treatment and Disposal of Irradiated Graphite and other Carbonaceous Waste (CARBOWASTE)". The project intends to develop best practices for the retrieval, treatment and disposal of irradiated graphite & carbonaceous waste and aims at closing the graphite cycle for future graphite moderated reactors. Besides coordinating the CARBOWASTE activities, IEK-6 investigates methods for decontaminating irradiated graphite.

Reactor safety: For analysing the consequences of accidents in nuclear power plants reliably, a profound understanding of the processes involved is required. IEK-6 develops and provides scientific methods and expertise to address safety issues of currently running reactors (LWR) as well as to assess the safety of advanced reactor concepts (Generation III+ and IV). The institute continuously extends its scientific expertise in the fields reactor theory, containment phenomena and processes, and CFD modelling. In the field of reactor theory, algorithms for the simulation of reactor physical processes are being designed. Furthermore, integrated code systems describing complex processes inside the primary circuit are being developed and applied. Based on the unique knowledge gained during the development of the German High Temperature Reactor (HTR), the institute is currently combining numerous single purpose codes for, e.g., reactor design and operation, fission product transport, or thermal hydraulics to provide an integral VHTR code package for GenIV reactors. In the field of containment phenomena and processes, activities focus on phenomena that play an important role in case of severe accidents in LWR. Numerous experimental facilities are being operated for studying the phenomena hydrogen distribution and recombination, wall condensation, and aerosol behaviour. By closely connecting experiment and simulation, models describing the phenomena are being developed. In this context, the CFD modelling plays an important role as horizontal activity combining thermal hydraulics with newly developed models for dedicated accident phenomena and reactor typical components. Among other cooperations on reactor safety, IEK-6 is member of the FP7 Severe Accident Research Network of Excellence (SARNET2).

The **coordination of the German Support Programme to the IAEA** is assigned to the division for nuclear waste management. While keeping the competences in the three key areas sealing and surveillance systems, nuclear measurement methods and techniques as well as satellite imagery processing and geo-information technologies, the re-organisation within FZJ promises new impetus on safeguards for geological repositories, both technically and conceptually, and nuclear material characterisation.

Last but not least, a key responsibility will remain to be the representation and cooperation within ESARDA, on the basis that FZJ has been a long-standing member organisation and supporter of ESARDA. Currently, FZJ is contributing to the VTM, C/S, KTM and Editorial Committee working groups. Via subcontracts, also the IS working group and the Reflection Group are being supported.

Acknowledgements

The authors would like to thank all colleagues from IEK-6 contributing to the paper.

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Reaching out (and in): An Overview of the EU's Cooperation Projects in the Area of Export Control

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1. Introduction

In its efforts to contribute to the international fight against the proliferation of weapons of mass destruction (WMD) and their means of delivery, the European Union (EU) has put into effect a number of policies and tools meant to tackle this global threat from various positions, as laid down in the EU's Security Strategy (2003). One measure considered vital in reducing the undesirable spread of such weapons is the implementation of an effective national export control system. A properly-functioning export control system helps to ensure that critical goods and technologies with a dual use (that is, they have both a peaceful and military application) do not land in the wrong hands leading to the development of potentially very dangerous weapons, nuclear and other.

Many countries, however, have not yet fully developed export control mechanisms that match the highest international standards. As a result, there exist important gaps within the global export control system which terrorists could exploit to acquire essential components for the construction of WMDs. The EU has, therefore, committed itself through various outreach initiatives to cooperate with strategically important third countries to help them develop their export control system into one that is at the same level as the most advanced systems in the world. These outreach initiatives are not only in accordance with the objectives articulated in the EU's Security Strategy, but tie in closely also with UN Security Council Resolution 1540 (2004), which establishes binding obligations on all UN member states with regard to taking and enforcing effective measures against the spread of WMDs.

Since 2005, the German Federal Office of Economics and Export Control (BAFA), the largest export control authority in Europe, has been tasked by the EU with carrying out its outreach projects in the area of export control. In its role as the implementing agent of these projects, BAFA is heavily supported by a large pool of EU experts, who provide their expertise in various areas related to export control, including licensing, customs, and the legal structure. Together, BAFA and this team of European experts have been entrusted with not only assisting third countries in strengthening and harmonising their export control systems, but also with reinforcing and expanding cooperation and political ties between the EU and its partners.

2. The outreach projects

The first of the EU's outreach projects in export control, called Pilot Project 2004, was implemented by the Stockholm International Peace Research Institute (SIPRI) and focused on the cooperation with a small group of Southeastern European countries. BAFA took over the responsibility of implementing the follow-up projects, including Pilot Projects 2005 and 2006 and the EU-Russia cooperation project, under which the number of partner countries grew to ten on three continents. Upon successful completion of these projects in 2007 and 2008 and as part of its Instrument for Stability, established in 2007, the EU once again mandated BAFA with carrying out the next export control outreach project called Long Term Programme (LTP), which has a duration of slightly less than three years and which is set to finish at the end of 2010. The LTP currently comprises 20 partner countries, including Albania, Bosnia and Herzegovina, China, Croatia, FYR of Macedonia, Georgia, Malaysia, Moldova, Montenegro, Morocco, Serbia, Tunisia, Ukraine, and the United Arab Emirates. BAFA is currently consulting with the EU concerning the next project to follow the LTP, which could also involve once again enlarging the number of partner countries.

In each case, while beginning a new project, the goal was to achieve a smooth transition from previous projects without interruption of the cooperation. The phases of the cooperation work with each partner country take a similar path beginning with a pre-assessment, followed by a needs analysis, the elaboration of an action plan, the actual training and implementation of activities, and, finally, the evaluation of the work done.

3. A five-pillar approach

The EU's outreach activities in the area of export control are grounded within a five-pillar structure, which addresses each of the five critical areas within export control:

Legal – Reviewing and analysing the national export control legislation in the partner country to assess its compatibility with the EC Dual-Use Regulation as well as with UNSCR 1540 obligations and international export control regimes makes up one branch of the technical support provided as part of these projects. The EU experts offer suggestions and recommendations as well as support for drafting legal texts in order to harmonise legislation with international standards (for example, in relation to control lists or catch-all provisions).

Licensing – This pillar centres on incorporating legal provisions into the administrative mechanisms and on the practical application of the legislation. Activities in this area include training licensing officers to assess licensing applications and risk indicators with regard to end-uses, establishing licensing authorities and/or building their capacities in terms of licensing processes, and enhancing inter-agency cooperation.

Customs – This pillar seeks to support and emphasise the close coordination between customs and licensing authorities, which arises from customs' role in monitoring, inspecting and assessing suspicious transfers. Activities under this pillar predominantly aim to train customs personnel and border guards on relevant export control issues related to customs, such as border crossing, risk management, enforcement of export control laws, customs clearance processes and commodity identification.

Awareness – Once export control processes are implemented, it is essential that acceptance and understanding of these and the obligations they entail be increased among those who are directly affected by them, including industry and the research community. Awareness activities also facilitate an ongoing exchange of information between authorities and industry, which is a crucial element of an effective export control system. Specific activities include industry outreach events and the writing and publication of an export control handbook.

Sanctions – To complete a full-functioning export control system, it is important that mechanisms be in place to enforce the export control laws. This pillar targets the judicial sector and focuses on establishing effective penalties, deterrents and proportionate sanctions for violations of export control laws. Activities under the sanctions pillar support or train representatives of the judicial sector and other groups involved in investigating and prosecuting export control violations, covering topics such as cases of violations in export control laws and regulations, administrative fines, and the nature of penalties.

One of the key objectives of all the projects has been to tailor the assistance programme to the individual needs of the partner countries rather than simply offering a generic solution. So, while the five pillars are meant to cover all aspects of export control, the conditions within a country might only allow or require one or two pillars to be implemented at a time, providing the basis on which other pillars can thereafter be built if deemed necessary. In addition to these activities, regular communication is maintained with the partner countries by means of various coordination meetings and bilateral talks.

4. Creating sustainable progress

The philosophy that underpins the implementation of activities within the framework of these projects is one of sustainability. This means using strategies that provide partner countries with the tools they need to carry on independently the work started under the assistance project, in conjunction with strategies that help diminish external factors that may hinder the long-term implementation of measures.

One important such strategy is regular and ongoing training of licensing officers and other officials involved in export control in response to the regular turnover of staff in export control authorities. It is useful to note here that though it requires regular training, a certain level of staff turnover is considered favourable and a crucial aspect of fighting corruption as it impairs the development of deeply ingrained relationships that could lead to such behaviour.

A second strategy for building sustainability that is increasingly being applied in the project as assistance with the partner countries progresses to a more advanced stage is the use of a "train-the-trainer" approach. Seminars using this approach aim to give qualified experts (especially in licensing, customs and industry) in the partner countries the necessary didactical skills so that they can themselves conduct export control training seminars in the same manner as is done by EU experts under the LTP. This gives the partner countries the tools they need to carry on work independently once the assistance has finished. Such seminars also have a powerful multiplier effect because one "train-the-trainer" workshop will lead in time to the training of a much greater number of officers than a single licensing training workshop.

Lastly, the focus of the project is shifting from uniquely providing country-level assistance to a broader regional approach that also considers aspects relevant to the region in question. This approach has a number of benefits. For one, it enables neighbouring countries to work cooperatively together, exchange information and implement similar and cohesive export control systems, thereby increasing the effectiveness of the systems. It also encourages countries mutually to enhance and support local capacities in their region, while spurring them jointly to secure their common borders.

5. Examples of cooperation

Below are a few brief examples of some of the work accomplished to date under the EU's various export control outreach projects:

- The work of the project had a positive influence in helping Albania establish AKSHE (Albanian State Export Control Authority), the country's main export control authority.

- Through the support and assistance of the LTP, Bosnia and Herzegovina developed a comprehensive export control system, which includes a revised export control law modelled after the EU legislation that was adopted at the end of 2009.
- Large industry outreach events, each with over 100 participants, have been organised in China within the framework of the project, raising awareness about licensing procedures, industry obligations, and government-industry relations.
- Within the scope of the project, Georgia has received assistance to draft a comprehensive export control legislation, modelled after the updated EC Dual-Use Regulation.
- The project cooperation with CAS (Serbian Customs Administration) resulted in the most elaborate and intensive development of activities in the customs pillar among all Southeastern European countries. The activities improved inter-agency cooperation and raised awareness of customs' important role in enforcing export controls.
- As Ukraine has been using multiple dual-use commodity lists, a large number of activities have been carried out to support the transition to a single dual-use commodity list, to assist in drafting the necessary amendments to Ukraine's export control legislation, and to provide practical training on implementing the proposed changes in day-to-day work. "Train-the-trainer" seminars have proven especially effective in raising awareness of these changes among a large number of customs officers.

6. Risks and challenges

It is important to acknowledge and address the risks and challenges that inevitably accompany a programme of this political and technical scope. Some of these risks and challenges include a lack of political will and commitment to implement an export control system in the partner country, corruption and economic hardship, burdensome bureaucratic procedures, and changes in leadership or contact points. However, these risks and challenges should not be seen as setbacks but rather as opportunities to improve laws and stabilise the political situation, reduce bureaucratic barriers, increase transparency and build confidence in the partner country. To make these opportunities possible requires long-term cooperation encompassed in an ongoing intercultural dialogue based on trust. Yet it is also important to always remain realistic and recognise that progress at a technical level may not necessarily translate directly into an equivalent transformation at a political level.

7. From outreach to inreach

Early in 2010, the European Commission issued an invitation to tender for a contract to develop a concept for a technical training course on dual-use export controls in the EU. While outreach projects to help third countries improve their export control systems were already in full swing, discussions in various forums and a study conducted in 2006 revealed the existence of an "implementation gap" in export control systems within Europe. Essentially, although great progress has been made in the past few years to develop an advanced EU policy on dual-use export controls, it was found that these top-level legislative actions have not consistently translated into an equally strong development at the implementation level. The result is that licensing and customs authorities in various EU Member States have different levels of expertise and sometimes dissimilar working methods that may negatively affect the reliability of an EU-wide export control system. It was as such determined that an inreach study project should be carried out, consisting of developing an idea for a training programme that would bring EU Member States' capacity to implement dual-use export controls up to the same level.

BAFA, with its extensive experience in outreach activities and large pool of EU experts, was awarded the contract. The focus of the training programme was established in two areas of action: 1) enhancing the expertise of licensing officials in the EU, and 2) providing technical training for EU customs officers, especially as regards commodity identification. The first step in developing a concept for this training programme is currently underway and involves identifying the precise training needs in the EU and working out suitable methodologies to meet these needs most effectively. In a second step, once the training concept has been fully prepared and set out, it will be tested by way of a pilot training session to be held in Brussels. The successful completion of this study will result in a training plan that can be used as the basis for organising a full-scope training course for the identified target audiences.

8. Concluding thoughts

The EU has fully engaged itself to combat the proliferation of WMD by working to strengthen export controls both within and beyond its borders. The results of the cooperation work under the Long Term Programme as well as under previous outreach programmes have been very positive so far, yet it is important not to become complacent as there is still much that needs to be accomplished. The process of establishing and/or developing an effective and efficient export control system is not a linear one, and, therefore, demands constant observation of movements and changes in the partner countries, as well as time and flexibility. For their part, the partner countries have also made clear that they expect long-term cooperation and the continuation of close working relationships with the EU. Recognising, however, that the support it can provide to other countries is only as good as its own expertise, the EU has moved forward with the groundwork for instituting an EU-wide training course in licensing and customs. In doing so, the EU demands not only from others but also from itself the highest levels of commitment to bringing about a more peaceful and secure world.

Reference

For more information about the EU's outreach activities in the area of export control, please, visit our website:
www.eu-outreach.info

Peer reviewed section

Global Trade Data to Support IAEA Safeguards

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Abstract

Motivated by the insight that trade data may support IAEA safeguards, a survey was conducted on world trade data available from open sources, resulting in a catalogue of web services on statistical and transactional trade data. Statistical data have a worldwide coverage and are provided, often for free, by international and governmental organizations and statistical offices. Services on trade transactions have a national or multi-national scope and are managed by companies.

Trade data may provide information to support the verification of additional protocol declarations and nuclear material transfers as well as give indications of possible undeclared activities. Since trade data are retrieved by Harmonized System (HS) codes used by traders to declare goods to customs, a condition for using these data is to relate items of interest to safeguards with appropriate HS categories.

The paper firstly reviews data services available on world trade with emphasis on type of data provided, geographical and temporal coverage. It then addresses the challenging task of correlating categories of items of interest to safeguards and HS codes, and presents a software tool developed for this goal. The paper concludes on possible uses of trade data for the purpose of nuclear safeguards.

Keywords: Safeguards; trade data; import/export; sensitive goods; additional protocol.

1. Introduction

Information on imports and exports to be declared to the IAEA under comprehensive safeguards agreements (CSA) [1] is limited to any source or special fissionable material defined in Article XX of the IAEA Statute. Source material does not include ore or ore residues. Following the disclosure of undeclared nuclear programmes in Iraq and DPRK, the IAEA sought to use other sources of information, including trade-related information, as indicators of possible undeclared safeguards relevant activities. This new strategy took shape in two ways.

Firstly, the voluntary reporting scheme (VRS) endorsed by the IAEA Board of Governors in 1993 provided a scheme for voluntary reporting by States of exports, imports and production of nuclear material and exports and imports of specified equipment and non-nuclear material, referring to the Nuclear Suppliers Group (NSG) trigger list[1] [2] published by the IAEA as INFCIRC/254/part 1 [3]. Later on, the 'additional protocol' (AP) to safeguards agreements [4] included requirements for new information to cover imports and exports of source material holdings, and information on exports of specialized equipment and material specified in Annex II of the AP[2], as well as a description of the scale of operations for locations related to a number of activities as specified in Annex I of the AP.

Secondly, the IAEA started to use information from open and other sources, including trade information, to reveal indicators of possible undeclared or incorrectly declared activities. The establishment of the IAEA Trade and Technology Analysis Unit (TTA) in the Department of Safeguards in 2004 has been instrumental in implementing this strategy.

Since 2005, IAEA General Conference resolutions have repeatedly called upon all States to support the Secretariat's efforts to verify and analyze information on nuclear supply and procurement provided by Member States, thus providing a clear mandate to IAEA in this area [5]. Further, the IAEA Medium Term Strategy 2006-2011 [6] clearly stressed that identifying new sources of trade-related information relevant to safeguards is a priority for the IAEA.

Collection and analysis of trade-related information is potentially useful for:

- The State evaluation process and for drawing broader safeguards conclusions[3];
- Verifying import and export declarations made by States under APs, article 2.a.(ix) [4];
- Identifying indicators of activities to be declared under APs, article 2.a.(iv) [4] or other nuclear fuel cycle activities.

[1] The so-called 'NSG trigger list' refers to items whose transfer from NSG Member States requires specific physical protection measures and IAEA safeguards agreements to be in place in the recipient State. The first trigger list was published in the guidelines issued 1978 [2]. The latest update dates to 2007 [3].

[2] Annex II of the additional protocol was derived from the NSG guidelines part 1 (1992).

[3] For each State with a safeguards agreement in force, a *conclusion* is drawn on an annual basis, relating to the non-diversion of nuclear material which has been placed under safeguards. For each State with a CSA and AP in force, a *broader conclusion* can be drawn that all of the nuclear material in the State remained in peaceful activities.

To serve these purposes, the IAEA is using State declared information (e.g., export declarations made by States under APs or CSAs), open source information, as well as information provided by States on a voluntary basis. Each source of information presents strengths but also limitations.

To fill knowledge gaps and cross-check information derived from different sources, the IAEA launched a procurement outreach programme [7][8], started developing new information analysis tools and methodologies [9] and improved understanding of the market of sensitive nuclear technologies. Exploring the use of world trade data for safeguards purposes is a continuation of these endeavours.

In this paper we investigate the value of using trade data to support safeguards. Section 2 of the paper reviews services available on world trade data with emphasis on type of data provided, geographical and temporal coverage. Since trade data are reported according to the Harmonized System (HS) nomenclature of goods by the World Customs Organisation, [10], a condition to use these data is to relate items of interest to safeguards with HS categories. This is addressed in Section 3. Section 4 presents a general methodology of how statistical trade data could be used for nuclear verification purposes. Section 5 presents a software tool developed to relate items of interest to safeguards with HS codes to facilitate the retrieval of relevant trade data. Finally, Section 6 concludes with a comparison of features of trade data with features of other information sources in use at the IAEA. A discussion on the value and limitations of using trade data in support to safeguards activities is also presented.

2. Data services on world trade

This Section illustrates data services that are available on world trade. These services provide 'open source' trade data, i.e. data that can be accessed by any individual either for free or after the payment of a subscription fee. Different from other open source information about trade (such as news and specialized trade press), the information covered by trade data services described hereafter has a regulatory origin: the data stem from declarations made by traders to customs authorities. These customs data are collected at the national level and, by decision of individual States, released under specific formats, which broadly fall in the two categories of transactional and statistical data.

2.1 Services on transactional data

Services on transactions are collections of data largely equivalent to original declarations made by importers/exporters to national customs authorities.

Published data fields subject to disclosure may include:

- A code classifying the commodity traded (e.g. according to the HS product nomenclature [10], see Section 3);
- Free text description of the commodity;
- Quantity, expressed in weight or number of items;
- Value;
- Date of shipment;
- Country/port of import/export;
- Party names.

The scope of transactional services can be national or multi-national. For countries where customs data are released, several services exist offering these data in various combinations. Some services provide additional information on the shipment's routing.

Figure 1 shows a map of countries for which collections of transactional data have been found to exist as a result of a survey [11]. For each country, an indication of the number of years of data available is shown. The earliest transactional data available starts in 1995 (for the United States, on imports only). Several States have started to release transactional data only in the last five years. It must be noted that the number of States publishing customs data is not necessarily increasing in a steady way: a State may decide to change its policy[4] for the dissemination of the data or considerably reduce its scope by suppressing key fields.

Services on transactional data are offered mostly by private companies against a subscription fee. This can be conspicuous, especially for services with a multi-national scope and offering a single interface point that allows querying many data sources at once. In general, the cost is a function of the data sources included in the service: the number of data fields, the number of product categories and country sources. Some services offer predefined combinations of data sets (with a fixed cost service), others allow for customized combinations of data sources.

Transactional data services can be delivered online or offline. Online services are the most common, and rarely offer archive data (e.g. data before 2004). For archive data, CD-ROM services are offered instead.

2.2 Services on statistical data

Statistical data on trade are derived by aggregating transactions data by country, trade flow (import or export), period of time (months, years) and product categories as specified by the adopted nomenclature, the most common being the HS [10].

Typically, a data record includes:

- Reporting country (the exporting or the importing country);
- Partner country in trade;

[4] Reflecting changing national provisions on data confidentiality.

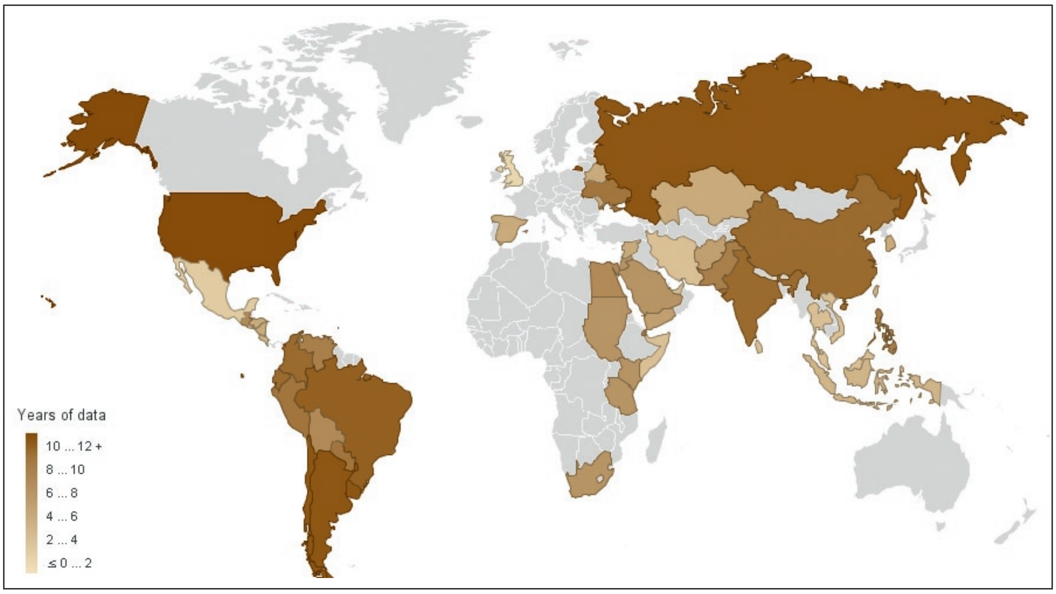

Figure 1: Services on trade transactions geo-located. For countries where transactional data are available (countries in shades of brown), the temporal coverage is expressed in terms of number of years of data released. Trade transactions cover imports and exports, except for Spain, UK and US for which only import data are available.

- Trade flow (import or export);
- Category of commodities (HS);
- Time period (months or years);
- Cumulative value of the trade for the above fields;
- Cumulative quantity of trade for the above fields.

The scope of statistical data services is in most cases multi-national. As an example, COMTRADE [12], provided by the United Nations, offers the largest geographical coverage, including 150 reporting countries with annual series of data. Archives date back to 1995 or earlier. COMEXT [13], provided by EUROSTAT, the European Union Statistical Office, is a second example: focused on EU reporting countries, it provides monthly records of trade data since 1995. Being based on monthly records, COMEXT provides finer time resolution than COMTRADE. On the other hand, COMTRADE gives a more global perspective on the world trade due to its higher number of reporting countries. Because COMTRADE includes bi-lateral statistics provided by countries partners in trade (imports versus exports), it is possible to estimate missing data by mirroring the statistics between partner countries, or analysing records with priority given to those provided by countries whose reports appear to be more reliable.

Statistical trade data are offered by international organizations, governmental organizations and national statistical offices, often for free or for limited fees. Private companies also provide access to these data as pay services. In this case, the cost of the service is justified by interesting combinations of data sets and powerful interfaces to search and navigate through the data.

The data collection supporting these services takes place at national level, together with the aggregation of the data. After aggregation, the national data is released in broader data services contributing to building a global perspective on trade (e.g., as for COMEXT and COMTRADE). Statistical data are shared by respecting data confidentiality requirements whose definition are country-specific. In the EU and in a number of other countries, the data used for the production of statistics are considered confidential when it allows statistical units to be identified (e.g., the value of a single shipment) either directly or indirectly [14]. Because the precise operational criteria used to decide which statistical data are to be considered confidential are fixed by national legislation, an important part of any data service is to provide the users with 'meta-data information' which documents the procedure for the data collection and data treatment before release.

3. Mapping items relevant to safeguards with HS codes

Most data available from trade data services are retrieved by Harmonised System (HS) product categories. Designed by the World Customs Organization, HS has become the reference taxonomy for commodities adopted by customs, trade associations and statistical offices in the majority of countries.

HS is based on about 5,000 commodity groups organized within 22 Sections in a hierarchy made up of:

- Chapters;
- Headings;
- Subheadings.

Each level in the hierarchy is identified by a HS code and an explanatory note. Codes are 2-digit for Chapters, 4-digit for Headings and 6-digit for Subheadings.

For example, the following sequence leads to a six-digit HS code for milling machines[5]:

84 → 8459 → 8459.61

Where, according to HS definitions:

84	*NUCLEAR REACTORS, BOILERS, MACHINERY AND MECHANICAL APPLIANCES; PARTS THEREOF;*
8459.	*Machine-tools, incl. way-type unit head machines, for drilling, boring, milling, threading or tapping (excl. lathes and turning centres of heading 8458, gear cutting machines of heading 8461 and hand-operated machines);*
8459.61	*Milling machines for metals, numerically controlled (excl. way-type unit head machines, boring-milling machines, knee-type milling machines and gear cutting machines).*

Since most trade data available (whether statistical or transactional) are reported by HS, a condition to access relevant data is to relate items of interest to nuclear safeguards with HS codes.

Generally, two approaches are possible.

The first is to browse directly the HS guided by its hierarchical structure or through a textual search on keywords to identify HS codes that describe items of interest, as shown in the example above. This approach requires specific expertise and technical knowledge of the commodities for which the HS code is sought.

The second approach is to consult "correspondence tables" compiled by experts associating HS codes to items subject, for example, to export controls. One such table is the European 'Correlation Table' mapping to HS items listed in the European Union Council Regulation setting up a Community regime for the control of exports of dual-use items and technology [15] [16]. A subset of this table concerns only items listed in the Nuclear Suppliers Group (NSG) Guidelines Part 1 [3] and Part 2 [17] and is presented in [18][19]. The Correlation Table is part of the 'Integrated tariff of the European Communities' (TARIC) available on a specific web site of the European Commission [20]. TARIC incorporates the Community legislation on trade concerning tariff suspensions, quotas, import/export prohibitions, surveillance, and trade restrictions. Within TARIC, the Correlation Table serves the practical purpose of informing exporters as well as customs officers in EU Member States about restrictions that apply to the trade of commodities listed in the EU Council Regulation on dual-use, which includes, among others, items subject to nuclear export controls[6]. A more specific explanation on how TARIC works is given in [19], together with a description of Combined Nomenclature codes which are a refinement of HS codes and used in TARIC.

Following the previous example, Table 1 shows some HS codes associated to 'milling machines' by the 'Correlation Table'. Querying TARIC for existing trade restrictions in the EU on all these HS codes retrieves a reference to the particular controlled item listed in Annex I to the EU Council Regulation on dual-use items, in this case item 2B201a, whose definition is shown in Figure 2.

Product code	Meaning
8457.10	Machining Centres, For Working Metal
8457.20	Unit Construction Machines (Single Stage) For Working Metal
8457.30	Multi-Station Transfer Machines For Working Metal
8459.10	Way-Type Unit Head Machines For Removing Metal
8459.31	Boring-Milling Machines Nes[7], Numerically Controlled For Removing Metal
8459.51	Milling Machines, Knee-Type Numerically Controlled For Removing Metal
8459.61	Milling Machines not elsewhere specified, Numerically Controlled For Removing Metal

Table 1: Some HS codes corresponding to 'milling machines' according to the EU 'Correlation Table'.

Comparing the detailed definition in Figure 2 with the descriptions provided by HS codes in Table 1, highlights the degree of approximation introduced by the HS codes. They do not discriminate between high precision machines necessary for nuclear end use from other less sophisticated machines used in other fields. Despite that, these HS codes are most likely used by exporters and importers also when declaring trade of high-precision milling machines to Customs. Under this hypothesis, their export will appear under these categories in trade databases together with other milling machines intended for different uses. One can expect favourable cases where actual trade on machines tools with nuclear end-use reported under these 'generic' HS codes can be recognized by other criteria, such as the trade unit value[8]. Note that the problem of 'disambiguating' trade data reported by HS codes is continu-

[5] This commodity is of potential interest to safeguards verifications because certain high-precision milling machines can be used to manufacture parts of gas centrifuges used for uranium enrichment.

[6] Annex I of EU Council Regulation on dual-use 'implements internationally agreed dual-use controls including the Wassenaar Arrangement, the Missile Technology Control Regime (MTCR), the Nuclear Suppliers' Group (NSG), the Australia Group and the Chemical Weapons Convention (CWC)'.

[7] NES stands for: Not Elsewhere Specified.

[8] Milling machines for nuclear end-use have characteristics and precision requirements that increase their cost.

2B001 Machine tools and any combination thereof, for removing (or cutting) metals, ceramics or "composites", which, according to the manufacturer's technical specification, can be equipped with electronic devices for "numerical control", and specially designed components as follows:

a. Machine tools for turning having all of the following:

1. Positioning accuracy with "all compensations available" equal to or less (better) than 6 µm according to ISO 230/2 (1988) (1) or national equivalents along any linear axis; and

2. Two or more axes which can be coordinated simultaneously for "contouring control";

Note: 2B001.a. does not control turning machines specially designed for producing contact lenses, having all of the following:

a. Machine controller limited to using ophthalmic based software for part programming data input; and

b. No vacuum chucking.

Figure 2: Definition of 'machine tools for milling' as in the EU Council Regulation on dual-use items and technology [16].

ously faced by customs authorities enforcing export control, whose first, indicative, 'risk assessment' is based on HS codes together with unit value and quantity indicators and other information specific to individual shipments.

From a technical safeguards perspective, it is recognized that the correspondence between items relevant to safeguards and HS codes is of uneven quality and weak for several items. As such, correspondence tables can only provide an indication on which HS categories trade of interest might have been declared to customs authorities. Nevertheless, there can be circumstances under which the use of HS codes to retrieve open source data about trade can be relevant for IAEA safeguards purposes.

4. Uses of statistical trade data services for safeguards

In the framework of the European Commission Support Programme to the IAEA, the JRC is conducting tests to assist the IAEA in the evaluation of possible uses of trade data services in support of safeguards implementation.

A sample test starts with a piece of information to be verified by the IAEA, for example, the export of a nuclear material from a country in a given timeframe. The goal of the test is to retrieve relevant data from sources on trade (presented in Section 2) for the IAEA to verify the correctness and completeness of the information in its possession.

Before consulting sources on trade, items of interest to the test case need to be clearly identified. This step is supported by trade and technology experts' advice and a set of reference documents where materials and technologies of interest are listed and described (e.g. the Additional Protocol [4], the Nuclear Suppliers Group Guidelines [3][17]). These items are then 'translated' into HS codes by correspondence tables and direct searches on the HS as explained in Section 3.

Having selected relevant HS codes, a plan of database queries is designed. Parameters that come into play in the planning are the geographical coverage of the test, the time frame addressed, the type of the data required (i.e., transactional or statistical), as well as the cost (if any) of accessing the data services or their usability.

For example, a typical query on a statistical trade data service would require the specification of the following dimensions:

- A reporting country;
- The HS codes related to the items of interest;
- A trade flow (import or export);
- A time period.

As a result of the query, the data service returns the list of partner countries for which trade on those dimensions has been reported, specified by quantity and value attributed to the trade.

Results of queries are then to be analysed by criteria specific to the test case. The analysis leads to the identification of a limited set of points of interest in the retrieved trade data. These data may confirm information known to the IAEA (completely or partially) and provide insights about its completeness. Figure 3 illustrates the concept of trade analysis applied to a safeguards case.

5. A tool for nuclear trade analysis

The identification of items relevant for consulting trade sources, as mentioned in the previous Section, depends on the consultation of several reference documents. These documents often describe the same items in different ways and with different levels of detail. Furthermore, each document has its own way of classifying and codifying the described items. In order to facilitate the usage of these documents in a coherent and efficient way JRC has developed a prototype tool called The Big Table (TBT). The goal of TBT is not only to identify, present and manage correlations between the items described in the collection of reference documents, but also to help the user identify the HS codes relevant to a particular item as described in Section 3, the identification of relevant HS codes being essential to the whole process.

The reference documents available within the current version of the tool are: the AP [4], a handbook on items listed in Annex II of the AP [21], the NSG Guidelines Part 1 [3] and Part 2 [17], the Goods Review List Annex 3 (GRL) [22] and its handbook [23], the European Union Council Regulation on dual-use items and technology [15] [16], and the Harmonized System [10] itself. Further revisions of these main documents are included.

The main user interface of TBT is illustrated in Figure 4. Using this interface, trade analysts can search items in the document collection either by text or by using the correspondence tables. In general terms, correspondence tables are intended to relate items listed in different documents of the collection.

Some correspondences identify *equivalent* items appearing in different reference documents. For example, milling machines referenced in the EU Council Regulation on dual-use as item 2B201a, are listed in the NSG Guidelines Part 2 as item 1.B.2.b: this correspondence is immediately made available by TBT. Other correspondence tables associate items described in some reference document to HS codes.

The tool provides automatic derivation of new correspondence tables by composition of existing correspondences. Given three documents D_1, D_2, D_3 and two correspondences $D_1 \rightarrow D_2$, and $D_2 \rightarrow D_3$, a third correspondence is derived between D_1 and D_3, by the application of a built-in composition operator, as follows:

$$D_1 \rightarrow D_3 = D_1 \rightarrow D_2 \rightarrow D_3$$

This is useful in different ways. *Firstly,* and in view of trade analysis, it is of interest to make relevant HS codes available to items in *whatever* reference document they appear. For example, the HS codes associated by the Correlation Table to milling machines in the EC Regulation on dual-use can be inherited by milling machines listed in the NSG Guidelines Part 2. It is sufficient to define equivalent items in these two documents (1.B.2.b → 2B201a) and compose this correspondence with the one provided by the Correlation Table (e.g., 1.B.2.b → 2B201a → 8457.10). *Secondly,* the composition operator facilitates the incorporation of revisions of documents that are already part of the collection. It suffices to define in TBT the correspondence between the new and old version of the document. This is easily done based on comparison tables that always accompany revisions of documents.

Finally, correspondences can receive analysts' annotations. For correspondences towards HS, the annotations record experts' appreciation on the strength of a link to HS in view of nuclear trade analysis. For example, links be-

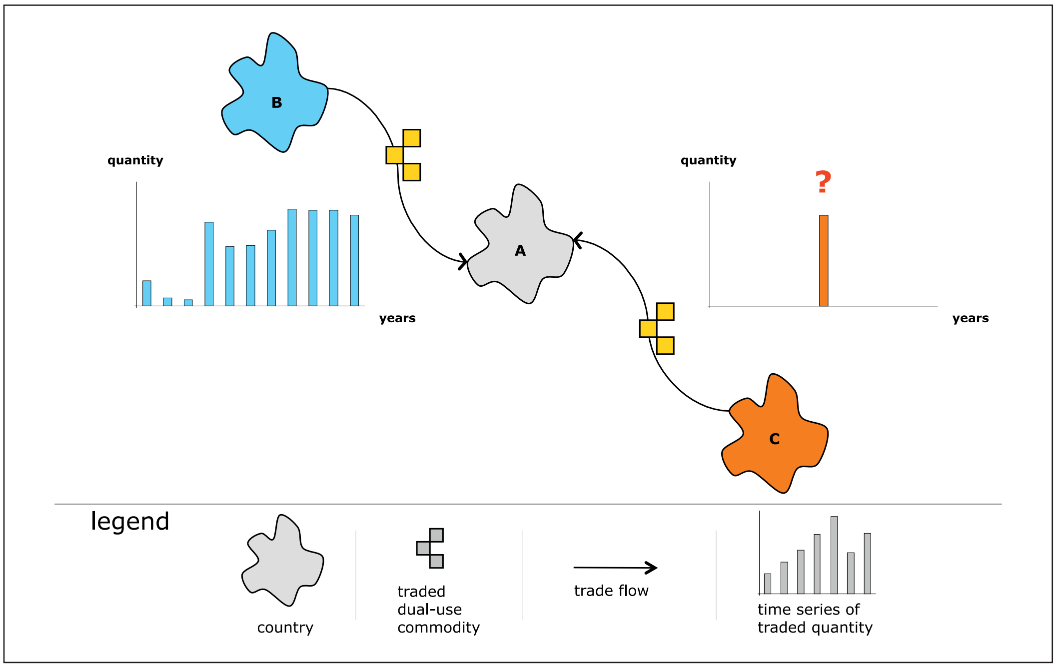

Figure 3: Trade analysis applied to test a hypothesis of undeclared activity. In this illustrative example, country 'A' is supplied regularly with a dual-use commodity by country 'B'. Country 'C' provided to country 'A' a single high quantity of the same commodity. This data point stands-out as it doubles the normal import pattern of Country A for that commodity. This oddity may call for investigations.

tween milling machines and HS codes listed in Table 1 can be annotated to be relevant when machines are traded at a high unit value.

6. Discussion and conclusions

Trade data services are to be seen as a complement to other sources of trade-related information used by safeguards. As an illustration, Table 2 summarizes, in a comparative way, some features of (i) trade information as declared by Member States to the IAEA, (ii) trade information retrieved from open sources, and (iii) trade information derived from the trade data services presented in Section 2.

Trade data services present several positive features:

- In comparison to other open source information about trade published by e.g. news and media, the data provided by these services are 'official', because they stem from declarations made by exporters and importers to customs. As such, the IAEA can, if needed, discuss these data records with competent States' authorities.
- The geographical coverage of statistical data is worldwide, a fact that opens the possibility of mirroring records between partner countries in trade (e.g. export published by exporting States and imports published by importing States) to complement missing data, or to compensate for reporting countries whose trade declarations appear to be less reliable. Moreover, trade data services may cover countries which do not have additional protocols in force and, as such, do not provide information on nuclear-related imports and exports to the IAEA.
- The data cover all commodities in trade; they are not limited to items to be declared to the IAEA under safeguards agreements. This feature may allow for the testing of hypotheses on possible undeclared activities whose indicators may be based on relevant commodities other than those declared by States to the IAEA.
- The data provided are of a quantitative nature (value and quantity of trade), a useful characteristic for analysis purposes, compared to unstructured open source literature.

[9] Some open source information can be considered as official, such as public court indictments.

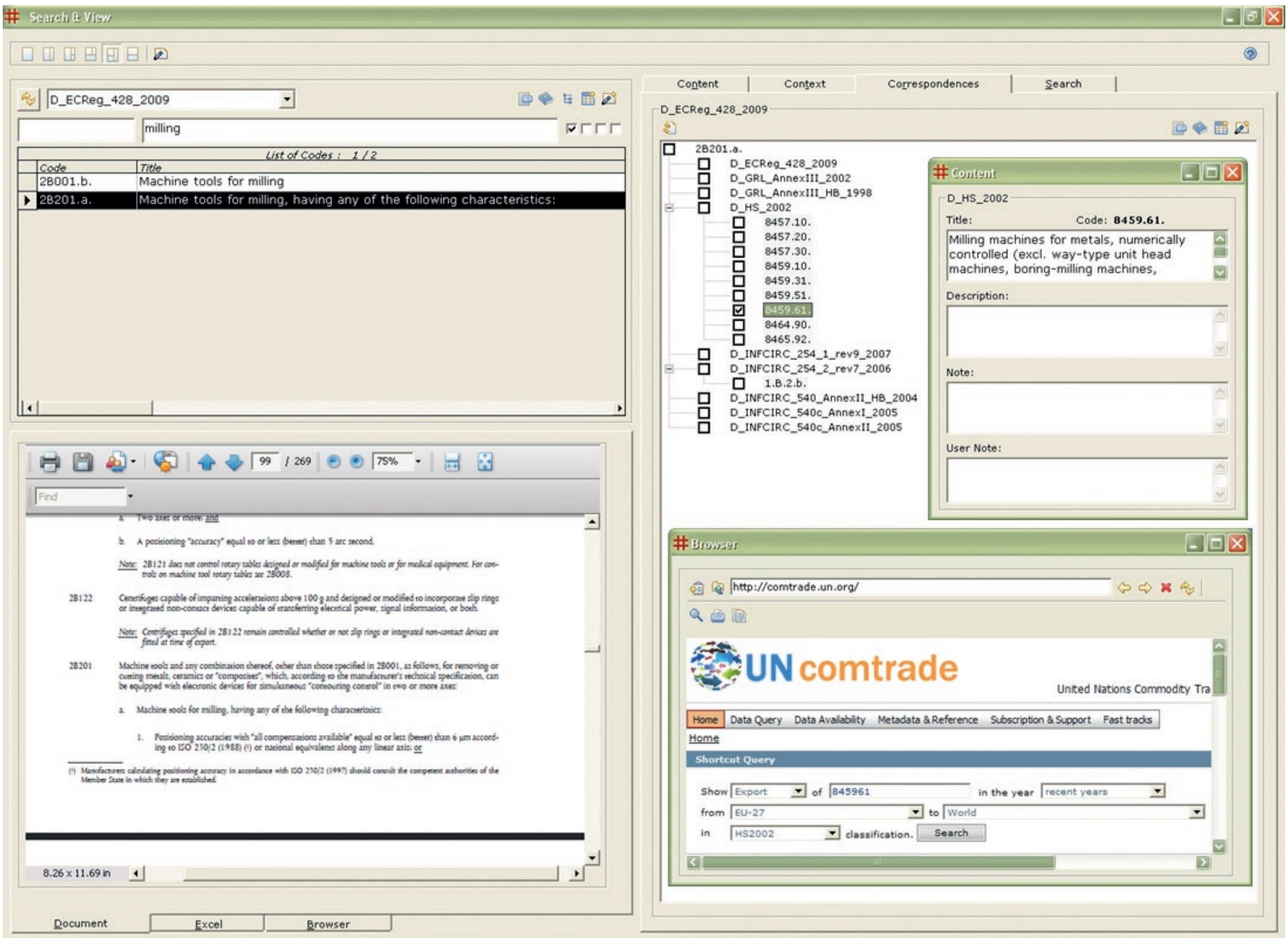

Figure 4: Interface of 'The Big Table' prototype tool for nuclear trade analysis. A document in the collection can be searched by text (top-left panel). Selecting an item of interest retrieves: (i) its definition in the original document (bottom-left panel); (ii) corresponding items in other documents of the collection (top-right panel). Among these, Harmonized System codes can be selected to query a trade data service (bottom-right).

Features	Information declared by States to IAEA	Information retrieved from general open source media	Trade information retrieved from trade data services
Source	State authorities.	Non-proliferation community, news media, etc.	State / customs authorities.
Nature of information	Official.	Non official.[9]	Official.
Geographical coverage	States with safeguards agreements in force.	All States, with an emphasis on States receiving media coverage.	All States inserted in the world economy, including the 150 States members to the World Customs Organization.
Items coverage	Nuclear material, AP Annex II Items when AP is in force.	All commodities.	All commodities.
Information type	Structured, referenced by IAEA legal definitions.	Unstructured, not referenced.	Structured, referenced by HS codes.
Temporal coverage	Starting from entry into force of safeguards agreements.	No limit.	Since the existence of electronic data bases. More recent (5-10 years) for detailed information.
Information update	Initial, yearly or quarterly declarations.	N/A.	Yearly, quarterly, monthly or by shipment.
Continuity	Regular.	Irregular.	Regular.
Import / export mirroring	For CSA and VRS: imports and corresponding exports are declared independently. For AP Annex II items: systematic declarations are due for exports only.	Often reflects one-sided information.	Imports and corresponding exports reported.
Reliability of information	*High* to verify correctness, *medium* to verify completeness.	*Medium* to *low* depending on the source.	*Medium* to *low*, depending on item types, value, trade flow, publishing State.
Accuracy of information	*High*.	*Medium* to *low* depending on the source.	*Medium* to *low*, depending on item types.

Table 2: Comparative table on selected features (first column) of sources on trade stemming from States declarations (second column), open source information (third column) and trade data services (fourth column).

- For statistical data services, the collection of records is generally complete over time: time series over more than ten years can be retrieved from data services and analysed.

A limiting factor in the use of trade data services appears to be in the granularity of the data. For several items of interest to Safeguards, HS codes may simply prove to be too generic to retrieve relevant trade data in a reliable and accurate way. On the other hand, there can be other means to 'disambiguate' the data retrieved by these codes (e.g., by indicators on the value of trade, by time series analysis, etc.). For other items, HS descriptions seem to be sufficiently accurate to provide medium accurate indicators about trade.

A second limitation is linked to the reliability of the information declared to customs by importers and exporters. Customs data cannot be expected to reflect fully the reality of trade. However a good understanding of the data coupled with an appropriate analytical methodology makes this source of information useful for safeguards.

The IAEA has not yet conducted a systematic evaluation on the use of these data. Initial use showed that shipments of material or equipment of interest to safeguards known to have taken place can be visible through statistical data. Further, these data contributed to answering important questions faced by safeguards. More specifically, initial tests on the use of trade data services suggest its safeguards relevance along the following lines:

- *Support the IAEA State evaluation process and improve understanding of a State's nuclear programme* – Trade information on exports can support the assessment of a State's nuclear related industrial capabilities. Data on trade flows between States can be used to understand their international cooperation. Understanding mining-related activities can be improved by using data on the exports of raw materials and semi-finished products. Data on imports and exports of nuclear materials and equipment may also provide information on the development of the nuclear fuel cycle in general.

- *Verify import and export declarations made by States under APs* – Trade databases can prove useful to identify trade flows of raw material subject to safeguards. HS categories appear to be less specific than safeguards categories, but precise enough to be determined as safeguards-relevant. The identification of shipments of some AP Annex II equipment may represent a greater analytical challenge.
- *Identifying indicators of activities to be safeguarded or to be declared under APs* – In this context it is foreseen that trade databases can be used to verify hypotheses about the absence of undeclared activities. Commodities to serve as indicators and methodologies then need to be identified on a case by case basis and in a hypothesis-specific way.

As a general conclusion, trade data services are not expected to provide on their own evidence of safeguards-relevant trade or activities, but indications complementing other sources of information received by the IAEA. They are fully relevant when part of a general analysis strategy, in line with the IAEA safeguards mandate. The Department of Safeguards is using them to clarify safeguards issues and provide an independent view on safeguards relevant developments in States. However full use of the new approach calls for additional analytical resources, increased awareness of its potential and an evaluation process of the methodology, including systematic feedback from follow-up activities.

Acknowledgments

The work here presented has been carried out within the European Commission (EC) Support Programme to IAEA by the EC Joint Research Centre, Action on Information Analysis for Nuclear Security, funded under the 7th Euratom Framework Programme.

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Novel Spectrometric Approach to Non-Destructive Characterization of Safeguards Samples

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Abstract

To improve non-destructive analysis of samples, a device known as PANDA has been designed and built. It has two measurement positions operating in a vacuum: one primarily meant for the screening of large-area samples, such as swipes, and the other one for detailed studies of smaller parts of these samples. The measurement position for the initial screening of large samples hosts a double-sided silicon strip detector and a broad energy HPGe detector. These detectors are positioned facing each other and the samples are measured between them. The data produced by the detectors are recorded as time-stamped events. The collected data together with supporting metadata are uploaded into a database for analysis and long-term storage. The present article primarily concentrates on the introduction of the tools and procedures developed for data management and analysis. The capabilities of PANDA are demonstrated via the analysis of a large-area swipe sample containing U and Pu. The swipe was provided by the IAEA. The ^{240}Pu/^{239}Pu atom ratio could be correctly determined (0.12 ± 0.03) in the presence of a large amount of ^{241}Am.

Keywords: NDA; particle analysis; coincidence technique.

1. Introduction

When searching for nuclear signatures from illicit activities or monitoring radioactive substances in the environment, various types of samples are being routinely collected and analysed by national and international bodies, see for example [1]. Samples containing radioactive materials are typically studied using experimental setups that only contain a single detector. This approach may easily lead to multiple measurements using different types of detectors, thus increasing the overall time needed for a complete assay. This approach also excludes the use of coincidence techniques.

Because of these limitations, a device called PANDA (Particles And Non-Destructive Analysis) has been built at the Finnish Radiation and Nuclear Safety Authority [2]. Besides being a fully operational instrument, PANDA can also be used as a development platform to study the performance of novel radiation detectors, measurement techniques and analysis algorithms. The present article concentrates on introducing the developed analysis software and the procedures for data management. As an example, the analysis of a reference swipe sample provided by the IAEA is presented.

2. Experimental techniques

PANDA consists of two vacuum chambers (Fig. 1a): the so-called loading chamber and the measurement chamber. These chambers can be isolated with a gate valve, so that while changing a sample in the loading chamber, the measurement chamber can be kept in vacuum. This obviates the need to switch off the bias voltages from the silicon detectors between the measurements. A sample to be measured is mounted onto the tip of a horizontally moving linear feedthrough. After evacuating the loading chamber and opening the gate valve, the sample can be transported to the measurement chamber. This chamber contains two measurement positions. The first one hosts an HPGe detector for the detection of gamma- and X-rays and a double-sided silicon strip detector (DSSSD) for alpha particles (Fig. 1b). The HPGe and the DSSSD face each other, and the distance between them is adjustable. The samples are measured between these two detectors. All measurements presented in this article were performed with this setup.

The position-sensitive DSSSD can be used to locate particles from large-area samples such as filters or swipes [3]. It has 32 front strips and 32 back strips. Each strip is 2 mm wide and 64 mm long, making the active area of the detector 64 × 64 mm_2. The front and the back strips form a grid of 1024 pixels with a pixel size of 2 × 2 mm^2.

Simultaneous measurement of the gamma-rays and the alpha particles using an event-mode data acquisition system enables alpha-gamma, gamma-alpha and also gamma-hitmap coincidence studies. As an example, a gamma-ray spectrum containing only gamma-rays that are recorded simultaneously with the alpha particles can be generated. Such spectra are nearly background free [4]. In addition, the knowledge that only the alpha-decaying nuclides are responsible for the generated spectrum makes its analysis simpler and more reliable.

The second measurement position has recently been completed, and it is devoted to detailed studies of smaller

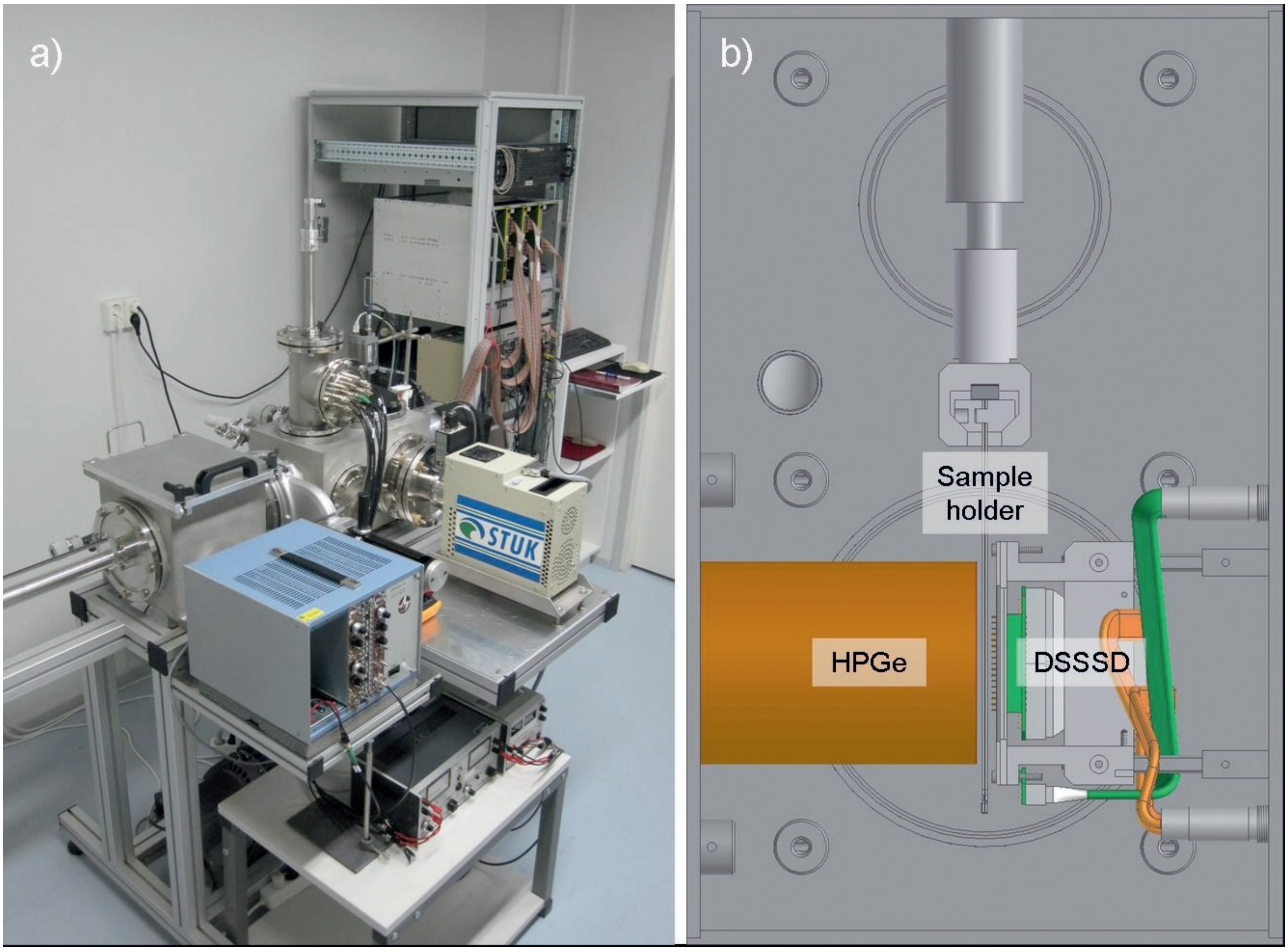

Figure 1: (a) The PANDA device. **(b)** CAD drawing representing the inside view of the measurement chamber and its measurement position 1.

samples and the most interesting parts of large samples, such as those containing radioactive particles. Currently, this experimental setup includes a single 10 mm^2 silicon drift detector that is installed onto the tip of a vertically moving linear feedthrough. By having both horizontal and vertical movements available, optimal positioning of the detector with respect to the sample is possible. The sample can also be moved back and forth between the two measurement positions.

After completing the measurements, the data are uploaded into a LINSSI 2 database for analysis and long-term storage [5]. In this process, supporting metadata is also uploaded.

3. Data management

The handling of data generated by the event-mode data acquisition system of PANDA is a challenge. Each recorded event also contains a time-stamp. In addition, these data are linked with administrative information such as the sample description and settings used during the measurement. Thus, it is clear that effective data handling tools have a crucial role in the analyses. In PANDA, all data are saved into a LINSSI 2 database with some additional tables for event-mode data [5]. Figure 2 illustrates the flow chart of the data handling.

The data acquisition system in PANDA saves the event-mode data in binary format supported by the acquisition control and online monitoring software. These resulting binary event files are converted to an easily readable Extensible Markup Language (XML) format. Then, these XML files are loaded into a MySQL database based on LINSSI 2. To reduce the amount of data saved in the database, the loading script allows the setting of criteria for the events to be saved. As an example, it is possible to save only those events where both the front and the back strips of the DSSSD have recorded a clear signal, or in addition, the HPGe signal could also be required in the event. Criteria such as these drastically reduce the amount of data loaded, and thus significantly speed up both the loading and analysis processes.

Traditional analysis software can only handle spectral data. Therefore, software is needed for the generation of spectra from the event-mode data saved in the database. For this purpose, software known as SPANDA was developed.

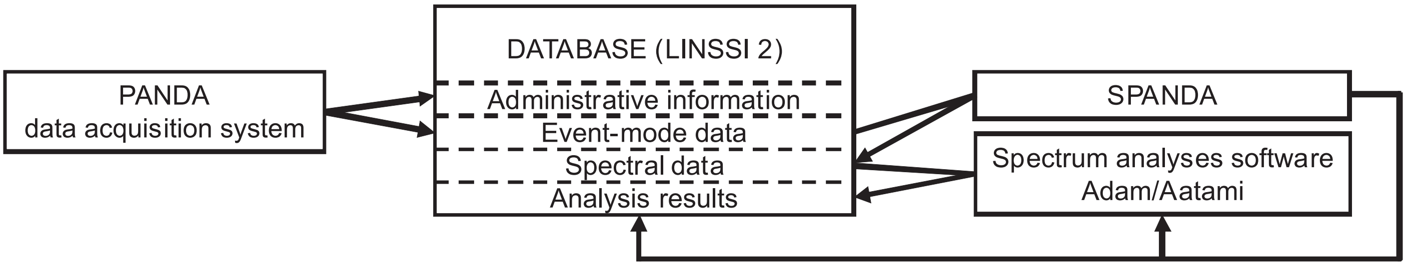

Figure 2: Data handling in PANDA. The recorded event-mode data along with additional metadata are stored in a LINSSI 2 database. These data can be converted to spectral data for the analysis. The final results are also saved to the database.

SPANDA reads the event information and saves it back in a spectrum format. Typically, various spectra with different properties are created from the same event-mode data set. The criteria for querying can easily be changed through a graphical user interface. Independent DSSSD gain matching and particle locating algorithms are implemented into SPANDA. The gain matching algorithm is important while creating alpha particle hitmaps or spectra employing several DSSSD pixels.

Finally, the generated spectra are fetched from the database and analysed with programs such as Aatami [6] and Adam [7]. Aatami performs gamma spectrum analysis using state-of-the-art algorithms. For example, a cubic spline is calculated for the baseline all over the spectrum. Aatami is designed for the analysis of extremely complex multiplets, including X-rays. This leads to improved detection capability and accuracy of results. Adam is an easy-to-use analysis tool for alpha spectrometry. In contrast to several other spectrum analysis codes, the alpha peaks of a nuclide are treated as a family of individual peaks with energies and yields obtained from a nuclide library. Versatile analysis tools allow efficient spectrum handling.

The analyses are performed separately for each spectrum. The analysis results are saved back to the database and linked with the original data. The parameters of the queries used while performing the analysis are also stored. The LINSSI database has an advanced structure for handling several measurements and analyses related to one sample.

4. Measurement and analysis of a swipe sample

Analysis of the reference swipe sample is presented below. The swipe was provided by the Department of Safeguards of the IAEA. The dimensions of the cotton swipe were approximately 10 cm × 11 cm. In the reference documents, the contents of the swipe were given as 1 µg of U and 10 ng of Pu. The certified ^{240}Pu/^{239}Pu ratio was 0.132.

The sample was first measured with PANDA for a long period (30.7 d). It turned out that the sample contained large amounts of ^{241}Am, which interfered with the Pu analysis. Therefore, a 300-µm-thick Ti attenuator was added between the HPGe detector and the source and the measurement was repeated (16.7 d).

The activity distribution of the sample was generated from the DSSSD data by using SPANDA. Figure 3 a) shows the total alpha particle hitmap of the swipe obtained after a measurement of 2 d. As can be seen, the radioactive material is unevenly spread over a large area. If a small amount of radioactive particles would be responsible for the hitmap, its shape would be significantly sharper [3]. Thus, the sample may have been produced by dropping radioactive liquid or powder onto a cotton cloth. Later investigations of the alpha spectrum showed that most of the radioactive material is deep inside the cloth. This observation further supports the assumption of the sample production method.

In Figure 3 b), only those alpha events have been accepted where a 59.5 keV gamma-ray was also detected. This hitmap shows the ^{241}Am activity distribution on the sample. The yield of the 59.5 keV transition and the gamma-ray detection probability related to each pixel have been compensated. As can be seen, the ^{241}Am activity distribution follows the same shape as the total activity distribution. In addition, the ^{241}Am activity explains only less than one third of the total activity on the sample. This indicates that the sample also contains some other radioactive isotopes that are distributed over a wide area.

The isotope analysis process was started by generating an alpha-gated gamma-ray spectrum from the event-mode data by using SPANDA. First, all pixels from the alpha particle hitmap were selected, allowing alpha particles hitting any part of the detector to act as a gate signal. This is reasonable, since the radioactive material on the sample is spread over a relatively large area. Selecting a smaller number of pixels would only reduce the number of alpha-gamma coincidence events, i.e., the statistics in the resulting spectrum would become lower.

If a sample contains a large amount of ^{241}Am, a difficulty in the analysis of the low-background gamma-ray spectrum is the true coincidence summing effect. Annoying sum peaks are caused by coincidences of low energy X-rays with each other and with ^{241}Am gamma-rays. When two photons are absorbed simultaneously, the detector electronics interprets them as a single event. Due to the high detection efficiency of the HPGe detector, the coincidence summing probability becomes significant. Since the gamma-ray yields of ^{239}Pu

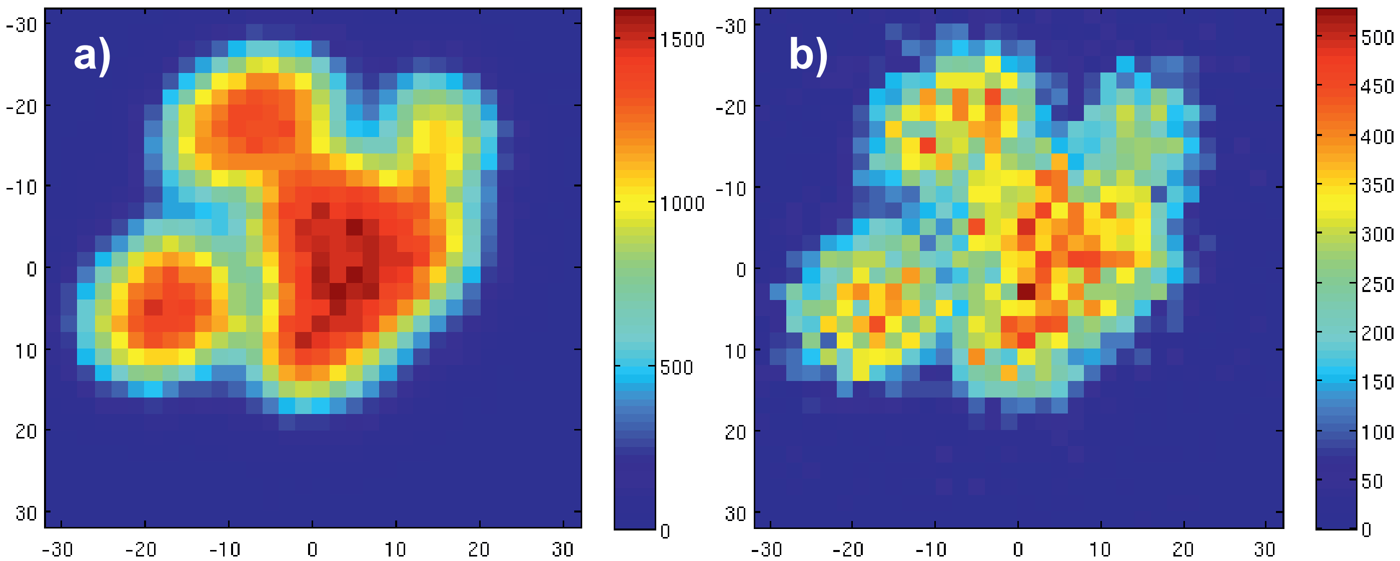

Figure 3: (a) Alpha particle hitmap of the IAEA swipe. **(b)** 59.5 keV (^{241}Am) gamma-gated alpha particle hitmap.

and ^{240}Pu are very small, even a small number of unwanted coincidence events can cause problems. The Ti attenuator absorbs most of the low energy X-rays, also reducing the X-X and X-gamma-ray coincidences.

Figure 4 illustrates the alpha-gated gamma-ray spectrum of the swipe measured both with and without the Ti attenuator. The number of counts per channel has been scaled according to the measurement time. Note that the large 59.5 keV ^{241}Am peak is not shown, and only part of the escape peaks around 50 keV are seen. The large interference caused by the 59.5 keV peak prevented the reliable use of the 51.6 keV ^{239}Pu peak in the analysis. In the spectrum measured without the Ti attenuator, the coincidence peaks overlap with the small ^{239}Pu (38.66 keV) and ^{240}Pu (45.24 keV) peaks and disturb the Pu isotope ratio analysis. In the measurement with the Ti attenuator, the low-energy X-rays are drastically absorbed and the contribution of the unwanted coincidence peaks is thus negligible. The attenuator also reduces the sizes of the ^{239}Pu and ^{240}Pu peaks, increasing the uncertainty of the peak areas. However, in this region there is no interference by ^{241}Am and therefore the statistical analysis is reliable. Based on the peak areas of the 45.24 keV ^{240}Pu peak and the 38.66 keV ^{239}Pu peak, the ^{240}Pu/^{239}Pu atom ratio was found to be 0.12 ± 0.03. This result is in close agreement with the known value. MCNPX was used for the generation of relative gamma-ray detection efficiency curves [8].

Compared to the relative activities, solving the absolute activities is more complex because the absolute alpha and gamma-ray detection efficiencies need to be known. In a coincidence measurement, the absolute efficiencies can be calculated from the measured data via comparisons of singles and gated spectra. The absolute alpha detection efficiency (ε_α) and gamma-ray detection efficiency (ε_γ) were determined from equations

$$\varepsilon_\alpha = \frac{A_{\alpha\gamma} b_\gamma}{A_\gamma b_{\alpha\gamma}} \qquad \varepsilon_\gamma = \frac{A_{\gamma\alpha} b_\alpha}{A_\alpha b_{\alpha\gamma}}$$

where $A_{\alpha\gamma}$, A_γ, $A_{\gamma\alpha}$, A_α are fitted peak areas associated to a selected isotope in the alpha-gated gamma-ray spectrum, singles gamma-ray spectrum, gamma-gated alpha spectrum and singles alpha spectrum, respectively. Likewise, b_γ, b_α and ba_γ are probabilities that the decay proceeds through a certain gamma-ray emission, alpha emission or through both gamma-ray and alpha emission.

Figure 5 a) presents the alpha spectrum of the swipe sample. Due to the absorption of the alpha radiation by the sample matrix, the quality of the alpha spectrum is poor, complicating the analysis of the resulting spectrum. The alpha spectra in Figure 5 were analysed with Adam [7]. The peak shapes used were obtained from the spectrum shown in Figure 5 b), which only contains counts from ^{241}Am. This spectrum was generated by accepting only those events where a 59.5 keV gamma-ray was also detected.

According to the calculus, the alpha particle detection efficiency of the measurement geometry was 5.4%. The absolute alpha detection efficiency was compared to the geometrical alpha detection efficiency (41%) which can be computed analytically [9]. Such a comparison provided useful information on the thickness of the sample. Only approximately 13% of the alpha radiation emitted towards the DSSSD was detectable.

The gamma-ray detection efficiency for 60 keV radiation was 20.0%. Therefore, the corresponding efficiency for the alpha-gated gamma-ray spectrum was 1.1%. For an ideal source (massless point source on the symmetry axis of a setup), this efficiency would have been approximately 10%. By using absolute efficiencies, raw estimates for absolute activities and masses were obtained (Table 1).

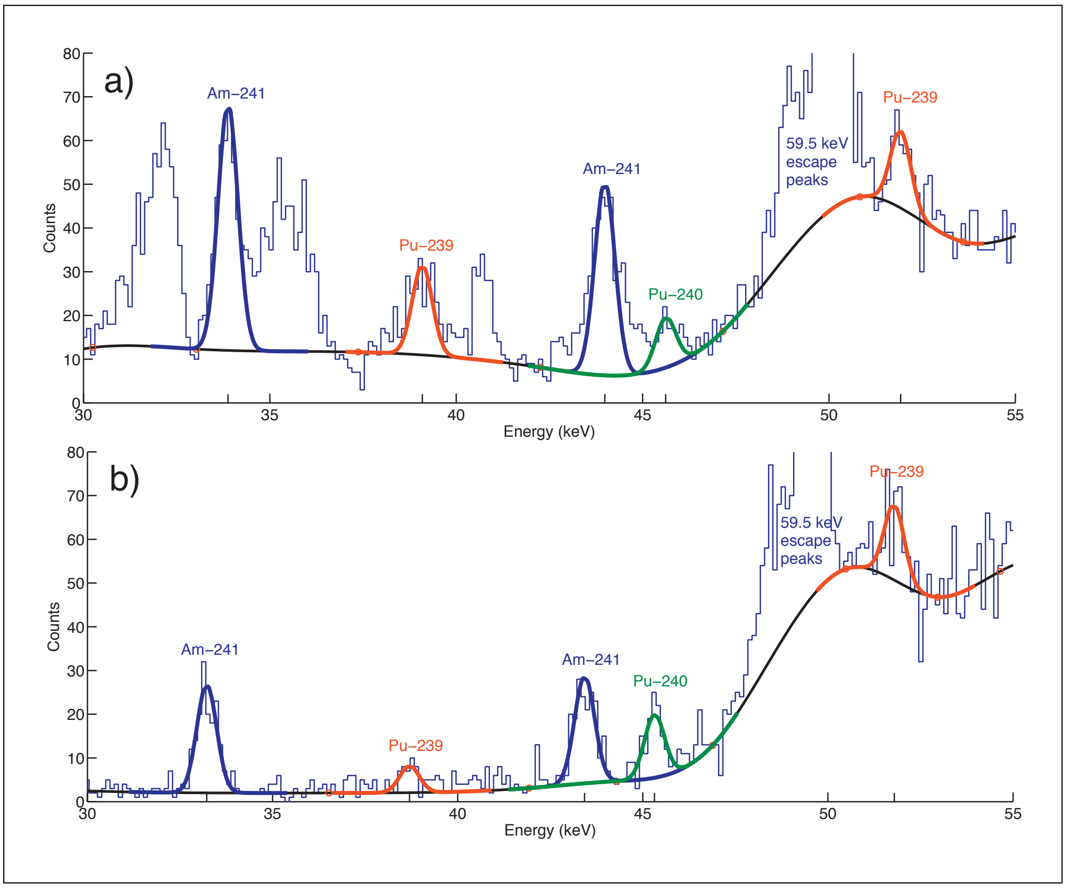

Figure 4: (a) Alpha-gated gamma-ray spectrum. Note the large disturbance caused by X- and gamma-ray coincidences. **(b)** Alpha-gated gamma-ray spectrum using a Ti attenuator. The spectra have been analysed with Aatami.

5. Discussion

The example case shown here reveals that PANDA is capable of determining the $^{240}Pu/^{239}Pu$ isotope ratio from a sample containing 10 ng of Pu located deep in the sample matrix. Realistic estimates for the absolute Pu activities were also obtained. The artificial swipe sample analysed was far from ideal and probably more difficult to analyze than many real swipes. Firstly, the swipe contained a great deal of ^{241}Am, which masked Pu by increasing the coincidence summing effect. Additionally, the large interference caused by the 59.5 keV gamma-rays of ^{241}Am prevented the reliable use of the 51.6 keV gamma-rays of ^{239}Pu. Secondly, a large part of the radioactive material was deep inside the swipe and only approximately one eighth of the alpha radiation emitted towards the DSSSD was detectable. If the sample would have been matrix free, only a tenth of the Pu concentrations would have been enough for the analysis. For example, a radioactive particle containing 1.6 ng of Pu was recently analyzed successfully with PANDA [10].

The techniques used in PANDA and demonstrated here can also be applied to make simpler coincidence setups. For example, a research programme applying alpha-gamma coincidence technique is going on at the IAEA [11].

For low-active samples a reliable isotope ratio analysis requires long counting times. However, successful screening of particles containing nanogram amounts of Pu can be performed in one hour. Within this time the particles can be located and the presence of plutonium revealed.

Acknowledgements

The authors would like to thank K. Vilece and B. Thekkinen of the IAEA for providing the swipe sample.

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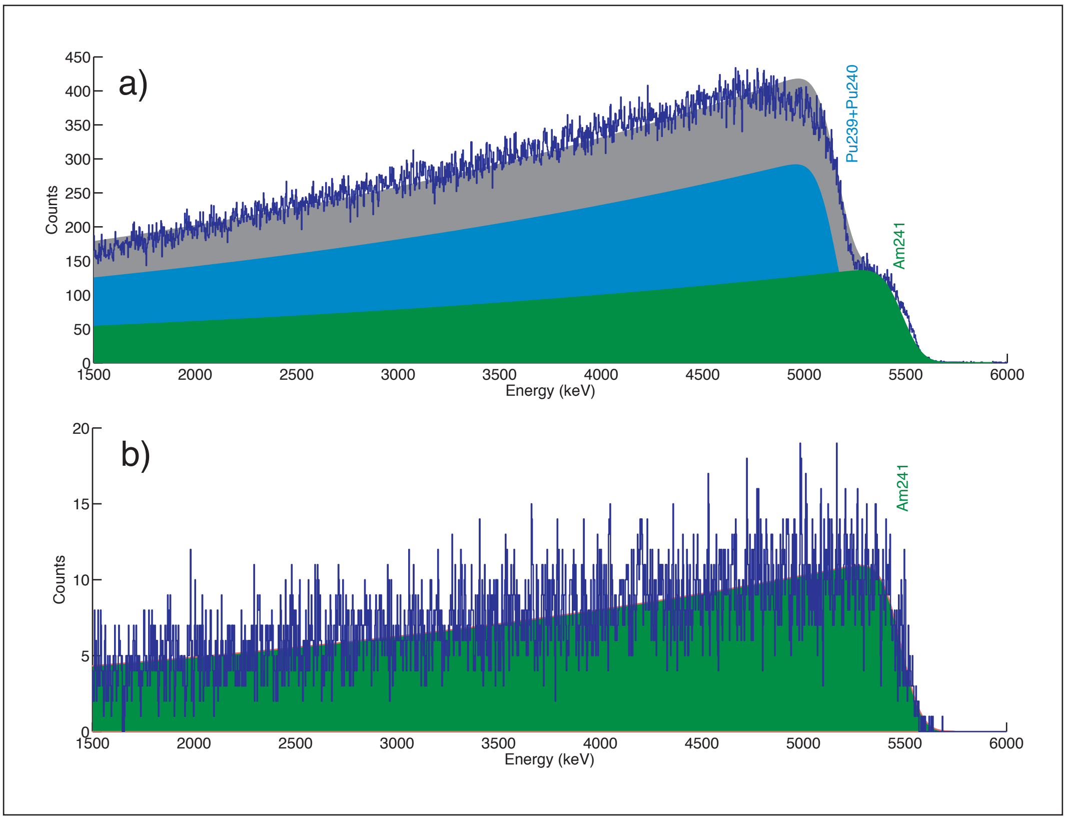

Figure 5: Summed alpha spectra of all DSSSD pixels obtained in a 2 d measurement. **(a)** Ungated spectrum. **(b)** 59.5 keV (^{241}Am) gamma-gated spectrum. The spectra have been analysed with Adam.

	IAEA (reference)	STUK
^{240}Pu/^{239}Pu atom ratio	0.132	0.12 ± 0.03
^{239}Pu activity	–	30 ± 8 Bq
^{240}Pu activity	–	15 ± 3 Bq
^{241}Am activity	–	16 ± 1 Bq
Total U mass	1 µg	-
Total Pu mass	10 ng	15 ± 3 ng
^{239}Pu mass	–	13 ± 3 ng
^{240}Pu mass	–	1.8 ± 0.4 ng
^{241}Am mass	–	0.13 ± 0.01 ng

Table 1: Analysis results of the reference swipe sample. The reported uncertainties are based on standard uncertainties, providing a level of confidence of approximately 68%.

Working Groups activities

Introduction to the NMAC Audit WG Outcome Report

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2. European Commission, DG ENER

The NMAC Audit Working Group commenced its work early in 2009, following an initiative of the European Commission, and completed the assigned tasks in May 2010.

According to the Terms of Reference, the main task of the ESARDA NMAC Audit Working Group was to check whether the audit criteria expressed in the Commission Recommendation of 11 February 2009, on the implementation of a nuclear material accountancy and control system by operators of nuclear installations (2009/120/Euratom), are applicable under real operating conditions in different facility types, and to give interpretation to these criteria wherever it was considered necessary. In addition, the WG was charged with other important tasks, such as giving advice to the safeguards community about the NMAC audit issues, and to make clear the role of the IAEA relating to NMAC audit.

Three documents constitute the outcome of the work and are published in this Bulletin:

- The audit criteria applicability and interpretation table.
- Establishment of the role of NMAC audit in the context of the safeguards cooperation between the European Commission and the IAEA.
- Final Report of the ESARDA NMAC Audit Working Group.

The main outcome of the Working Group's activities is the audit criteria applicability and interpretation table. In this table it is stated whether, or not, each criterion is applicable for the different facility types. Along with the applicability, advice is given for nuclear operators in the form of best known practices, and also advice for the auditor in the form of information related to the criteria fulfilment that could be requested.

The role of NMAC audit in the context of the safeguards cooperation between the European Commission and the IAEA is an exhaustive analysis of the legal basis, and potential benefit, for IAEA participation in the Commission's NMAC audits.

The Final Report expresses guidelines, comments and individual views about the audit conduct. It is a common understanding that audit can contribute to continuous improvement of a nuclear facility NMAC system. Therefore, the cases where audit is considered appropriate have been identified. During the work, controversial discussions occurred and the WG members could not find a unanimous agreement on the final report contents. This demonstrates the need to collect experience and results from further audits prior to performing a possible extension of the guidelines to the conduct of the audit.

The common thread of the three parts is the definition of the term "audit", its scope and appropriate audit cases definition.

In addition, in this report, the WG recommends learning from future audit activities and, if or when appropriate, to update the audit criteria and their interpretation, also taking into account any technical advances. It also advises the Commission to issue a document explaining the doctrine of NMAC audit in the framework of Euratom safeguards.

Applicability and Interpretation of Audit NMAC Criteria

The following table is intended to provide advice and to clarify the criteria laid down in the Commission Recommendation of 11 February 2009 on the implementation of a nuclear material accountancy and control system by operators of nuclear installations [1]. This Recommendation was built upon the model described by the ESARDA NMAC AF Working Group and after wide consultation between nuclear operators and Member States representatives. The Recommendation is intended to provide an assessment baseline to the Commission (audit criteria) and also to provide a model to nuclear operators for a high quality NMAC system. A number of the criteria of the Recommendation go beyond the requirements of the Commission Regulation (Euratom) No 302/2005 of 8 February 2005 on the application of Euratom safeguards [2].

The table has 4 columns:

- **Criteria.** On this column each criterion laid down in the Recommendation has been laid down.
- **Applicability.** On this column it is noted the applicability of each criterion for the different installation types.
- **Interpretation.** This column is intended to provide clarification to nuclear operators about the practices that can be followed to fulfil the criterion.
- **Subjects to be discussed during audit.** This column is intended to give advice to NMAC auditors on which information should be collected verify the fulfilment of the relevant criterion.

For each criterion and when relevant, the table is divided in three rows, the first one for bulk handling facilities, the second one for item facilities, and the third one for other facilities.

The table is divided in five sections as the Recommendation. In the first section, the management of the NMAC system, reference is made to the ISO 9001:2008 [3] standard very often. It is to be noted that when an operator has implemented a certified Quality Management System fulfilling with the requirements of this standard, and it includes the NMAC activities, most of the criteria should be fulfilled. However, NMAC auditors can not rely completely in an ISO 9001 certification, given that the NMAC activities are not very often between the main activities covered by the QMS of nuclear operators, and given that the intended NMAC audits will be very much focused on the NMAC system. When an operator has implemented a measurement system and measurement control system according to the standard ISO/IEC 17025:2005 [4], it can be assumed that the requirements of section 2 are in its majority fulfilled. However, it will always have to be checked whether the accreditation scope covers all the measurement activities regarding the NMAC system (including item counting and calculations). The standard ISO 10012:2003 [5] can also serve as a guideline for those organizations that do not wish to pass an accreditation process.

It should be noted that this table should be a changing document. Progresses and improvements made both in the NMAC activities and in the audit process should be incorporated to the table.

The table is intended to be flexible, given that there are a lot of ways to fulfil the requirements that are not identified on it. This flexibility must also be seen for auditors who may ask for information not mentioned in this table.

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Section 1: The Management of the NMAC system

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
Senior management should ensure that responsibilities and authorities are defined and communicated within the organisation.	Yes	Organisation Chart, internal communication, job description of the NMAC group member(s) or any other written and correctly distributed relevant document(s) within the organization.	Organisation chart, function descriptions, documented authorisation, justification for authorisation, staff interviews.
A member of the management should be appointed who, irrespective of other responsibilities, should have responsibility for annually assuring the chief executive officer in writing, that the entire NMAC system is fit for purpose.	Yes	A member of management (good examples are Radioprotection or Quality responsible) should be nominated (for example by means of the job description), and given the global responsibilities of the NMAC activities. A report should be written annually informing the chief executive officer (for example, tabling the report at the annual QMS review meeting is valid, but also any other way of giving the information to the CEO).	Record of the official nomination, record of the previous reports. It should make clear the awareness of the chief executive officer.
Management roles and responsibilities taken together should also comprise organizational procedures and communication patterns that:			
a) Transmit information about NMAC performance both hierarchically and across functional responsibility areas.	Yes	Documented communication channels (internal notes, meetings…) should be implemented to ensure that relevant staff is aware about NMAC performance when relevant. (department related to NMAC activities as Quality or measurements…, but also NMAC department staff or staff directly reporting to NMAC responsible, or staff performing NMAC activities).	Check documentation of communication patterns and channels and check records of any relevant issue that should have been communicated.
b) Assign responsibilities for improvement of NMAC as required based on criteria for recognizing when improvement is needed.	Yes	Someone (i.e. the NMAC responsible) should have the responsibility for setting up the means of NMAC improvement and the way(s) to recognize when this improvement is needed. There must be a record of the assignation of this responsibility. (Written internal note, job description…).	Check that the responsibility has been formally assigned; check that the criteria and activities for recognizing when improvement is needed have been set. Check that the assigned person has really taken the responsibility on him/her.
c) Provide the NMAC manager with NMAC anomalies information.	Yes	It should exist a procedure, instruction… Describing how information of anomalies is provided to the NMAC responsible. It should be taken into account the most normal sources of anomaly detection (non-conformities during operation, internal audit, indicators check…).	Check if it is documented how the anomaly information flow should be and check (by means of records) that this is really working.
d) Ensure staff involved in NMAC activities have the appropriate competences.	Yes	Normally, this is ensured by means of training programmes.	Check that Internal Training records, Training policy, training procedure(s), Training contents, certificates of individuals (participation / success), Measurement of success, training programme assessment is performed and includes NMAC competencies.

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
e) Ensure appropriate awareness of the legal obligations concerning safeguards.	Yes	For staff involved in NMAC it should be one of the basic competences and so it should be covered by the previous requirement. It should be ensured also that top management is aware of legal obligations related to safeguards.	Check whether the legal obligations have been transmitted to all concerned staff. Interview some of the staff to check the real awareness.
The key tasks should incorporate quality assurance and quality control measures. The objectives of these measures should include:			
a) Reduction of the intrinsic risk of human errors.	Yes	Automation of data handling should be implemented where possible and effective. Second checks and other Quality control measures should be documented and implemented where needed.	Check that automatic tool are used where possible, and that checks are in place where needed. This criterion may be part of a general feeling of the system. It should be checked in the documentation review and if non conformity is found should be on an specific element of the NMAC system.
b) Ensuring the correct functioning of instrumentation and software.	Yes	When instrumentation is used for measurement is covered by Section II, and when software is used for data handling, it is covered by Section V. specific criteria exist in these chapters.	This criterion may be part of a general feeling of the system. It should be checked in the documentation review (check if there are calibration and verification procedures, or if software is validated against pre-stated criteria) and if non conformity is found should be on a specific element of the NMAC system.
c) Provision of a variety of indicators designed to alert management to any sign of inadequate performance (performance indicators).	Yes	It should be documented how performance indicators are going to be calculated, criteria defining poor performance from the indicators results, actions to take in case of bad results, and track record of indicators results. Examples of indicators could be: • MUF figures • Number of anomalies • Number of corrections in software • Number of remarks after inspections	Check that performance indicators are provided to the NMAC responsible, that they are properly calculated, properly recorded and properly used.
d) Internal assessment in order to detect poor performance.	Yes	An internal assessment programme should be in place that covers all the main tasks. It should include the schedule, the responsible to carry out audits and the audit criteria to use. Records of the internal audits should be kept.	Check that an internal assessment programme exists and that it covers the main NMAC activities and it is carried out in a professional way. Check the records of internal audits, and check if the results are used to improve the system.

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
e) A corrective action mechanism for cases of poor performance.	Yes	There should exist a documented mechanism (procedure, instruction…) describing who, and how to act in case of detection of anomalies, or non-conformities… Records of these actions should be kept and also of the potential subsequent preventive actions to avoid recurrence.	Check that the mechanism is in place, but also that it is used as described (records of anomalies and corrective actions).

Section 2: Measurement and Measurement Control

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
Where measurements are performed, a programme should be established for providing sufficiently, accurate and precise quantification and characterization of the material that will be referred to in accounting declarations.	Yes, but only partially to item facilities.	Bulk handling facilities should have a measurement system compliant to the criteria of this chapter. To accomplish this, the ISO/IEC 17025:2005 and ISO 10012:2003 can serve as guide and help. Item facilities should only apply the criteria where accountancy declarations are based on calculations (i.e. burn-up declarations in power reactors) This applies for the whole section 2.	When an accreditation on standard ISO/IEC 17025:2005 covers the complete measurement system, the only check to perform is to verify that the measurement methods under the accreditation are the ones used for accountancy declarations. Interpretations to ISO/IEC 17025:2005 will be as much as possible those of European Co-operation for Accreditation.
Measurement activities will be conducted so as to have traceability in the event of investigation of an anomaly.	Yes	Records of every activity related to measurements should permit to reproduce exactly how, who, when and under what conditions it was made. Templates for records should take this criterion into account. A system to archive records should be documented and implemented.	Check a sample of records of measurement activities. Check the completeness. Check is an archiving system has been documented and correctly implemented.

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
In order to ensure appropriate performance of the measurements, the following should be taken into account:			
a) Validation of the applied measurements methods.	Yes	Measurement methods completely covered by recognised international standards or normative documents (EN standards, ISO standards, OIML Recommendations, ESARDA published measurement methods) do not need to be validated. (This does not imply that metrological validation should not be performed). Any other method should be validated according to pre-stated performance criteria. The validation study should be documented and recorded and made available under request. In the case of nuclear power reactors the calculation codes for the burn-up are considered as validated by the provided. It should be ensured that the code is used under the conditions allowed by the validation and using the correct data.	Validation studies and reports should be checked to compare planned/achieved performance parameters, and verify statistical tests for acceptance (normality, u-scores, calibration lines, …) measurement data (spectra), procedure for and results of uncertainty estimations, ruggedness test data, … It should be checked the way the calculation codes are used (benchmarks).
b) Traceability of measurement results.	Yes	Here traceability should be read as metrological traceability as it is defined in the International Metrological Vocabulary [6] by the BIPM (Bureau International de Poids et Mesures) 'property of a measurement result whereby the result can be related to a stated reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty' i.e. the measurement results must be traceable to units of the international system when possible, by means of traceable calibrations.	Check calibration procedures, calibration records (= documented results), calibration range coherent with measurement range?, calculations, logbook entries, non-conformities, re-calibration after non-conformity, … Reference materials as stored (storage conditions), certificates (value, uncertainty, confidence interval), records of intermediate checks, person(s) responsible.

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
c) Precision and accuracy.	Yes Except for item facilities.	Here precision is (VIM) closeness of agreement between indications obtained by replicate measurements on the same or similar objects under specified conditions' and should be assessed during the validation study, equipment reception, conditions change verifications… by means of the performance parameters repeatability and/or reproducibility. Here accuracy is (VIM) 'closeness of agreement between measured quantity values that are being attributed to the measurand, the concept measurement accuracy is not given a numerical value, but a measurement is said to be more accurate when it offers a smaller measurement uncertainty'. To assess accuracy, measurement uncertainty should be calculated. This should be done according to the GUM Guide (ISO, OIML, BIPM, …) [7]. Limits on uncertainty should be pre-stated, and it should be assessed not only during validation, equipment reception…, but on a regular basis for every measurement.	Check that the concepts of precision and accuracy are understood and implemented. Check that they are assessed by for example, comparison planned/ achieved performance parameters, statistical tests for acceptance (normality, u-scores, calibration lines, …) measurement data (spectra), procedure for and results of uncertainty estimations. Check that every measurement result is accompanied by its uncertainty calculated according to the GUM Guide concepts.
d) That each measurement result is approved by a responsible person.	Yes	It should be defined who is responsible to approve each measurement results.	Check that there is a designated person, check that s/he is competent enough, and check that s/he is approving the results and associated uncertainties.
e) That sampling is representative of the material.	Yes	When sampling is performed there should be a sampling plan and sampling procedures based on statistical considerations. Sampling and the sampling technique should be recorded.	Check the existence of a sampling plan and procedures, and check its application.
In cases were accounting data are based on calculations that are not direct measurements the values should be validated, traceable and approved. Similar requirements apply to item counting	Yes	The calculation method applied should be documented and technically justified. It should be validated with real data when possible. The results should be approved by a nominated responsible person with competence enough to judge on their validity. Every activity should be recorded.	Check the validation report, technical justification, records. Check the nomination of a responsible person.

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
A measurement control program is required in order to ensure the validity and the uncertainties of the measurement results used for accountancy declarations.	Yes	The nuclear facility should have documented procedures for monitoring the validity of the measurement results to be used for nuclear material accountancy. The criteria to assess the results must be preset. Statistical tools should be used when possible. The programme should be subject to review and improvement. It should include regular use of certified reference material, participation in intercomparisons, replicate tests, and retesting.	Visual inspection of QC samples, documented QC criteria, results of QC measurements (check against criteria), intercomparisons results, evaluation and conclusions, treatment of "out-of-limit" cases, correction + corrective actions, Records from replicates and re-measurements, application of acceptance criteria, follow-up of results Records of statistical considerations (e.g. control charts), documented follow-up of out-of-control situations.
The measurement control programme should include:			
a) Measures to ensure that the instrumentation is performing as required.	Yes	The measurement control programme should include a calibration and verification plan for instruments used in measurements used for accountancy purposes. Verifications and calibrations should be performed according to procedures in force ensuring metrological traceability. Calibration uncertainty should be estimated according to proper methods (following GUM [7]). Verification and calibration parameters should be preset in advance. Routine checks should be also planned when needed. Actions to solve nonconformities should be foreseen. Follow-up and history of every relevant instrument should be ensured by means of a records system.	Check procedure for and records of calibrations and intermediate tests, calculations, fulfilment of calibration conditions (e.g. regression lines), history of calibrations and checks versus specification, user logbook, maintenance plan, maintenance records according to plan, malfunctioning records, non-conformities, corrections, corrective actions, …
b) Assurance that accountancy mass values are free from any significant measurement bias and that the measurement uncertainty is appropriately estimated.	Yes	The measurement control programme should include measures to ensure that factors influencing measurements are under control in special: • Instrumentation and equipment • External conditions • Human factors • Measurement methods. Measurement uncertainties estimation methods should be documented. They should include every component which are of importance in a given situation and should guarantee metrological traceability of measurements and calibrations. GUM [7] should be followed.	Check that measurement control programme includes verification reports, definition of performance parameters, proof of achievement of performance, statistical tests for acceptance (normality, u-scores, calibration lines…). Check that staff members are properly qualified for performing measurements, calibrations, verifications. Check that external conditions are controlled when relevant (instrument working under calibration range). Check that method validation covers the measurement range and that instruments are used according to the validated method.
c) Records of all data of measurement control.	Yes	Every activity performed should be properly recorded, following a records approach or system that should be documented.	Check that a records system (including description of the way of recording and responsibilities assigned) is documented and implemented.

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
d) Description of the measurement equipment and methods.	Yes	Measurement procedures according to measurement methods should be in place and should be known and understood by people performing measurements. Instrument instructions when relevant to the measurement results should be available for instrument users. Every instrument should be followed up from reception to state 'out of use'. Every activity performed on it should be recorded and traceable.	Check standard or literature where method(s) is(are) described, procedures/instruction(s), performance parameters, manuals, … Check some instrumentation records.
e) Approval of the measurement procedures.	Yes	A procedure for approval of measurement procedures should be in place. This general procedure should cover from the research of solutions for measurement problems to the validation of the method and approval to the procedure describing the method.	Check the general procedure(s) for measurement method validation and measurement procedure approval. Check some measurement procedures and the traceability of the changes performed on the method. Check the consequent validation studies.

Section 3: Nuclear Material Tracking

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
The nuclear material tracking should document any movement of and the location of every item of nuclear material. It also implies knowledge of the characteristics of the material in question and its containment. Any action involving nuclear material that affects the location, the identification, the nature or the quantity of the nuclear material should be documented.	Yes	The NMAC system should be able to provide location, identification, quantity and characteristics of every nuclear material in the installation at any time. Any change on these features of the nuclear material should be recorded. Regulation 302/2005 [2] requirement.	Sampling different items, or batches of material to check if the NMAC system is able to provide complete information about it. Check records of changes of location, identification, nature or quantities in nuclear materials.
In particular tracking should include records that are the basis for re-batching, new measurement, shipper-receiver difference and category change declarations.	Yes	There should be templates for recording all these operations. It should be documented when these operations are to be applied. Regulation 302/2005[2] requirement.	Check if it is documented when these operations apply. Check that records are complete.

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
Nuclear material should, where practical, be in containers having a recorded unique identity. When nuclear material is not in a transportable container, a well delimited process location may be considered both as identity of the 'container' and as the location of the container/material. This includes material in process vessels or other equipment.	Yes	The NMAC documentation (procedures, instructions…) should define and describe a way to identify uniquely the nuclear material all around the installation. This identification should be the same as the identification of the location when processed material.	Check the NMAC documentation to identify nuclear material. Check that it is correctly applied.
Identities of containers must be permanent and readily legible for inventory checking. If the identity of the item needs to be changed, the link between old and new identities should be recorded.	Yes	Self explicative criteria. (Regulation 302/2005 [2] requirement for PIV.)	Check records of item identification change.
If nuclear material is in some form of double containment, the nature and the characteristics of the material in any container should be traceable through identification control.	Yes	When multiple containments are possible in the installation, the NMAC system should be able to provide the characteristics and quantity of nuclear material by means of identification of any of the containers.	Check that the required information is available if there are any multiple containments.
The locations in which nuclear material can be held must have identities that are a basis for recording the location and transfers of material.	Yes	The different locations should be defined and identified on the NMAC documentation. This could be specified in the BTC (Basic technical Characteristics).	Check that the different locations have been defined and check the identification. Check if the identifications are used for recording the location of nuclear material.
Specific positions within areas should be mentioned, where appropriate, as part of the specification of the exact location.	Yes	When applicable (e.g. cooling pools, storages…) identification of the specific positions should be part of the information provided by the NMAC system for the location of nuclear materials. This could be specified in the BTC.	Check if there is a way to identify specific positions where applicable and if this identification is used to locate the nuclear material.
The records for storage control should ensure that the identities of the contents of each storage location are known and that the location of any identified item can be derived.	Yes	When there is storage, the NMAC system should be able to provide identification, quantity and nature of nuclear material present in every specific location of the storage. Records of nuclear material movements into the storage, out of the storage, or between different positions of the storage should be kept. (Regulation 302/2005 § 8b [2] requirement.)	Spot check of some specific positions and the ability of the NMAC system to provide complete information. Check movements' records.
The nature and characteristics of the material in any location should be available through identification control or other means.	Yes	The NMAC system should be able to provide location, identification, quantity and characteristics of every nuclear material in the installation at any time. (Regulation 302/2005[2] requirement.)	Check if the NMAC system is able to provide complete information of nuclear material, only with the provision of the identification.

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
When nuclear material enters a process (or is repackaged), the production records should allow identification of the items from which the material has been fed into the process (or into new containers). This is intended to provide traceability of the relevant nuclear characteristics of the material in process.	Yes	Self explicative criteria.	Check if the NMAC system is able to provide complete information of material that has been introduced in a process or repackaged.
Production records should specify the amount of material fed into the process or repackaged and, as mentioned, traceability of information related to the nature of the nuclear material must be maintained.	Yes	Self explicative criteria.	Check if the NMAC system is able to provide complete information of material that has been introduced in a process or repackaged.
When new items or sets of material arise as a result of processing or repackaging, mass values and identities must be established for these items and their identity should be linked to the relevant mass results and measurement history.	Yes	Self explicative criteria.	Check if the NMAC system is able to trace back the material from the product to the row material in the installation.
Inventory control by the nuclear operator should:			
a) Ensure that all nuclear material transfers from stores to process areas and vice versa are recorded.	Yes	There should be a documented process to control that transfers of nuclear material into the installation are correctly recorded.	Check that there is a documented process to control that transfers of nuclear material into the installation are correctly recorded. Check records.
b) Verify regularly that stock records corresponds to KMP flow records, storage location records and processing records and regularly reconcile local records and central MBA records.	Yes	A regular interval for records matching should be defined, and records matching check should be performed following a documented procedure, instruction, etc…	Check that records matching is performed according to a documented procedure.
	No		
c) Take into account the operating records of those inventory control measures that ensure continuity of knowledge about the nuclear material contents of items.	Yes	The NMAC system should take into account items under seal while performing inventory control.	Check that records of sealed items are kept.
d) Regular check for agreement between the information of material present and the physical reality.	Yes	The inventory control by nuclear operators should in a proportionate way include physical checks of inventory, else than PIT. Depending on the type and size of installation, this requirement could go from nothing to random programmed checks based on a risk assessment.	Check that the inventory control by the nuclear operator includes physical checks of the inventory. Check that the way to perform these checks has been documented and check records of these verifications.
e) Resolving and reporting on found discrepancies and reconciliation with other local accounts or central accounts.	Yes	The inventory control should include or refer to a procedure /instruction, for resolving and reporting discrepancies fulfilling the requirements of ISO 9001:2008 [3] chapters 8.3 and 8.5.2, and ISO/IEC 17025:2005 [4] chapters 4.9 and 4.11.	Check the procedures for and records of non-conformities and corrective actions.

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
In the event of a transfer of nuclear material that is not a transfer of a contained item, the amount of the transfer material should be measured.	Yes	Self explicative. It should be documented which methods and instruments are used for this purpose. All the requirements of Section II apply.	This requirement should be checked during the documental review in the BTC's. Records of the measurements should be checked.
	No		
The installation should have an approach that recognizes and investigates NMAC discrepancies and documents their treatment. The approach should:			
a) Indicate for each discrepancy type the investigative actions to be taken and the conditions in each case that are considered to resolve the discrepancy. Actions to be taken should include personnel responsibilities and the additional data to be employed.	Yes	Sometimes, discrepancy types cannot be characterized because they are very rare. The approach should include or refer to a procedure / instruction, for resolving and reporting discrepancies fulfilling the requirements of ISO 9001:2008 [3] chapters 8.3 and 8.5.2, and ISO/IEC 17025:2005 [4] chapters 4.9 and 4.11.	Check the procedures for and records of non-conformities and corrective actions.
b) Make the appropriate correction of records and regulatory declarations when a discrepancy has been resolved.	Yes	The approach should include or refer to a procedure / instruction, for resolving and reporting discrepancies fulfilling the requirements of ISO 9001:2008 [3] chapters 8.3 and 8.5.2, and ISO/IEC 17025:2005 [4] chapters 4.9 and 4.11. (Regulation 302/2005 [2] requirement.)	Check the procedures for and records of non-conformities and corrective actions.
c) Record when a discrepancy remains unresolved and the action taken to resolve it.	Yes	The approach should include or refer to a procedure / instruction, for resolving and reporting discrepancies fulfilling the requirements of ISO 9001:2008 [3] chapters 8.3 and 8.5.2, and ISO/IEC 17025:2005 [4] chapters 4.9 and 4.11. (Regulation 302/2005 [2] requirement.)	Check the procedures for and records of non-conformities and corrective actions.
The installation should have an approach in place that corresponds to the reporting obligations under Article 6 and Article 14 of the Regulation Euratom) No 302/2005. In addition to the management of discrepancies described in point 6 of Section 5 of this recommendation, the approach should:			
a) Recognise, investigate and document the treatment of NMAC anomalies corresponding to Article 15 (a) of Regulation (Euratom) No 302/2005. Such NMAC investigations should aim to establish in a timely way the accountancy evidence that all material is accounted for.	Yes	There should be a procedure explicitly describing this case and the way to act.	Check the existence of the procedure and its application. (records)
b) Recognise, investigate and document the treatment of other situations corresponding to Article 15 (b) of Regulation 302/2005.	Yes	There should be a procedure explicitly describing this case and the way to act.	Check the existence of the procedure and its application. (records)

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
c) Define personnel responsibilities and the form of internal communication required when actions under Article 15 (a) or (b) of Regulation 302/2005 are required. The approach should also define the mechanisms under which the personnel will inform the Commission.	Yes	Self explicative.	Check the responsibilities definition and the process to inform the Commission description.
d) Define personnel responsibilities and authority in order to provide "further details or explanations" when requested under Article 14 of Regulation 302/2005.	Yes	Self explicative.	Check the responsibilities definition and the process to inform the Commission description.

Section 4: Data-processing System

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
A data processing system should be implemented producing:			
a) Safe and secure storage of all data required for the proper working of the NMAC system.	Yes	Standard security and safety tools as access records and access right, as well as automatic back-ups should be enough for the data processing system.	Check that these measures are in place. If not a justification by means of a risk assessment is needed.
b) Declarations required by Regulation (Euratom) No 302/2005 (inventory change reports, material balance reports, physical inventory listings, special reports, advanced notifications).	Yes	The data processing system in place should be ready to produce the required declarations.	Check that the declarations are produced by the data processing system, and not anyhow else.
c) Material balance standard deviation for material balance tests (if appropriate).	Yes	Self explicative.	Check that the balance standard deviation is produced by the data processing system, and not anyhow else.
	No		
d) Various types of documents linked to inventory change (IC) declarations such as shipping documentation.	Yes	Self explicative.	Check that the documents are produced by the data processing system, and not anyhow else.
e) Working documents for routine inventory control.	Yes	Self explicative. E.G: LII (List of Inventory Items).	Check that the documents are produced by the data processing system, and not anyhow else.
f) Working documents for PIT.	Yes	Self explicative. E.G: LII (List of Inventory Items).	Check that the documents are produced by the data processing system, and not anyhow else.
g) A List of inventory items (LII) resulting from PIT and used during PIV or other verification.	Yes	Self explicative.	Check that the documents are produced by the data processing system, and not anyhow else.

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
Data-processing procedures should be in place to correct records and generate correction declarations as appropriate, for any situation where a discrepancy has been detected. Traceability should be maintained during such correction processes. Quality control and quality assurance should ensure the completeness and the correctness of the data-processing system.	Yes	There should be a procedure/instruction to describe the way of dealing with discrepancies. The procedure should guarantee traceability of corrections.	Check the procedures for and records of non-conformities and corrective actions.
The data-processing capabilities should also include:			
a) Provision of inventory lists permitting inventory checking by the operator.	Yes	Self explicative.	Check that the documents are produced by the data processing system, and not anyhow else.
b) Inventory lists providing any information necessary for identifying discrepancies between the locations described in the records and the real physical location.	Yes	Self explicative.	Check that the documents are produced by the data processing system, and not anyhow else.
c) Support of regular reconciliation of local records and central MBA records, when the accountancy of nuclear material in process involves separate storage of these records.	Yes	The data processing system should be able to perform this match verification when there is this double records-keeping system. (ISO 17799:2005 [8] requirement)	Check the capability of the DP system when this is the case.
d) The possibility of including corrections arising from discrepancy investigation for inventory checking and reconciliation.	Yes	There should be a procedure/instruction to describe the way of dealing with discrepancies. The procedure should guarantee traceability of corrections.	Check the procedures for and records of non-conformities and corrective actions.
e) Documentation of the results of inventory checking and database reconciliation including documentation of discrepancies encountered for the purpose of performance indicators.	Yes	The DP system should be able to receive information from physical verifications, and records matching and treating it with the purpose of providing performance indicators.	Check this capability and records.
The procedures for data-processing execution activities should provide the NMAC system manager with supervisory information. This should include the staff member initiating each software execution, identify the application program(s) involved as well as identify the location of the data inputs used and location of the data outputs created. It should also be possible to identify any execution of application software or access to records and data which do not conform to the authorized data processing policy.	Yes	Self explicative. Basic security requirement. (ISO 17799:2005 [8] requirement. – traceability).	Verification of logs and activities with the NMAC manager.

Section 5: Material Balance

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
Nuclear operators should apply reception procedures including:			
a) Check of shipper information (completeness, self-consistency).	Yes	There should be a procedure describing the activities to perform when nuclear material is received in the nuclear installation. These activities should include the check of the receiver information.	Check reception procedure and records.
b) Check of the nature, identity and integrity of the transport container and seals and initial check on the nature of nuclear material (when appropriate).	Yes	There should be a procedure describing the activities to perform when nuclear material is received in the nuclear installation. These activities should include the physical check of the nuclear material when appropriate.	Check reception procedure and records.
c) Introduction of the received material into the accountancy process.	Yes	There should be a procedure describing the activities to perform when nuclear material is received in the nuclear installation. These activities should include the introduction of the material into the accountancy.	Check reception procedure and records.
d) Recognition and treatment of shipper-receiver differences.	Yes	There should be a procedure describing the activities to perform when nuclear material is received in the nuclear installation. These activities should include activities and criteria to detect shipper-receiver differences.	Check reception procedure and records.
e) Corrective actions in the event of discrepancies.	Yes	There should be a procedure describing the activities to perform when nuclear material is received in the nuclear installation. These activities should include the corrective actions to be taken in the event of discrepancies.	Check reception procedure and records.
f) Recording in a way to guarantees traceability.	Yes	There should be a procedure describing the activities to perform when nuclear material is received in the nuclear installation.	Check reception procedure and records.
g) Ensuring that the obligations laid down in Articles 21 and 22 of Regulation (Euratom) No 302/2005 are respected.	Yes	There should be a procedure describing the activities to perform when nuclear material is received in the nuclear installation. These activities should ensure that Art. 21 and 22 of Regulation 302/2005 [2] are respected.	Check reception procedure and records.

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
Nuclear operators should apply shipping procedures defining:			
a) The content of the information being sent to the recipient.	Yes	There should be a procedure describing the activities to perform when nuclear material is shipped from the nuclear installation. These activities should include the check of the information to be sent to the receiver.	Check shipping procedure and records.
b) How the accountancy should be updated.	Yes	There should be a procedure describing the activities to perform when nuclear material is shipped from the nuclear installation. These activities should include the update of the accountancy.	Check shipping procedure and records.
c) Corrective actions and the appropriate response to situations of discrepancy indicated by the recipient.	Yes	There should be a procedure describing the activities to perform when nuclear material is shipped from the nuclear installation. These activities should include the corrective actions to be taken in case the recipient informs of discrepancies.	Check shipping procedure and records.
d) The preparation and execution of the shipment process.	Yes	There should be a procedure describing the activities to perform when nuclear material is shipped from the nuclear installation. These activities should include the physical check of the shipped material when appropriate.	Check shipping procedure and records.
e) Record keeping in a manner that guarantees traceability.	Yes	There should be a procedure describing the activities to perform when nuclear material is shipped from the nuclear installation.	Check shipping procedure and records.
f) Activities to ensure that the obligations laid down in Articles 21 and 22 of Regulation (Euratom) No 302/2005 are respected.	Yes	There should be a procedure describing the activities to perform when nuclear material is shipped from the nuclear installation. These activities should ensure the respect of Art. 21 and 22 of Regulation 302/2005 [2].	Check shipping procedure and records.
A physical inventory of each MBA should be taken every calendar year and the period between two successive physical inventory takings should not exceed 14 months. The PIT procedures should include those for reporting to the Commission and providing LII for physical inventory verifications. In particular, nuclear operators should have PIT procedures taking account of the following needs:			
a) Definition of PIT working methods and responsibilities for each storage and process area.	Yes	There should be a procedure/instruction defining and describing clearly the activities to perform in order to take the inventory on every material present in the installation and who is responsible for each activity.	Check PIT procedure(s) and records.
b) Establishment of a reliable itemized list of all the material in each location of the MBA. Such procedures should be designed to ensure that no material is overlooked.	Yes	The basis for the PIT work should be an itemized list of all the material present in the installation. The way to establish this list (information to be included, where the information comes from, …) should be described in a procedure/instruction.	Check PIT procedure(s) and records.

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
c) The execution of the physical inventory taking needs to be recorded.	Yes	The PIT procedure/instruction(s) should describe the way all the activities during PIT are going to be recorded.	Check PIT procedure(s) and records.
d) If there are PIT activities involving physical checks (tag-check or measurement), the procedures should include rules for defining the necessary corrections to the information in the data processing systems (when discrepancies are found) as well as rules for transmitting (in written or orally) these corrections to the DP department.	Yes	The PIT procedure/instruction(s) should include a description of the actions to be taking in case of discrepancies found between the working list and the physical reality.	Check PIT procedure(s) and records.
e) The MBA LII being presented to Commission inspectors as a basis for PIV should be authenticated by the signature of a responsible person before being handed over.	Yes	Self explicative Electronic transmission with identification acceptable.	Check PIT procedure(s) and records.
f) In a PIT approach for a storage area relying entirely on transfer records the credibility of the approach in these cases should be enhanced by having, (i) QC and QA provisions for the creation of records of transfers, (ii) QC and QA ensuring reliable records of storage locations, (iii) Routine recording of the fact that these QA and QC provisions and measures had been carried out, (iv) assurance of material integrity during presence within the area(v) independent confirmation that transfer records are complete.	Yes	When the inventory is only based on records due to the fact that physical verification is not possible, QA and QC measures should be in place to ensure the correctness of the PIT. These measures should be described in the procedures/instructions. (iv) is in the scope of the physical protection	Check PIT procedure(s) and records.
The LII for formal verification purposes should include for each item:			
a) Location and storage position within location.	Yes	Self explicative.	Spot check of LII.
b) Type of container and identity of container (if relevant).	Yes	Self explicative.	Spot check of LII.
c) Material type.	Yes	Self explicative.	Spot check of LII.
d) Mass of nuclear material per item (gross, tare and net weight.	Yes	Self explicative. Applicable when relevant (not for process vessels).	Spot check of LII.
e) Enrichment of U.	Yes	Self explicative.	Spot check of LII.
f) Isotopic composition of Pu (if available).	No		

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
The LII should include entries for material that is difficult to measure either due to its location (process vessel hold-up) or because it is in a form unsuitable for measurement. In such cases, the operator must declare an estimated range of mass for each item and the traceability must provide the link to the data that have been used for the estimate. Mass estimates for material that is inaccessible or in process vessels should include the location of the material. The mass values for measured discards, accidental losses and transfers to waste should have a traceable history.	Yes	When this is the case, the value given should be the result of a justified estimation process. The technical justification to the estimation should be documented, and the data used for it should be traceable. Not applicable for item facilities	Check that there is a reliable technical justification to the estimation and that the described process to it is followed.
In an MBA involving processing or re-measurement, the Material Balance derived from a PIT and also the process area material balances forming part of an inventory control approach, should be tested for acceptance using balance standard deviations that take account of justified measurement uncertainty and in the case of estimated amounts, the process and measurement uncertainty. These tests should be an integral part of the QA system.	Yes	MUF and σMUF calculation should be part of the PIT procedure/instruction. σMUF must be calculated based on justified measurement uncertainties or estimations uncertainties. The material balance test is just a comparison between MUF and σMUF.	Check that MUF and MUF and σMUF calculation are part of the material balance procedures/instructions. Check that the calculation of σMUF is based on legitimate uncertainties. Check that material balance test is performed.
	No		
The procedures for any balance test should take account of the following needs:			
a) Software for computing the standard deviation of any balance should come under the quality approach for software and its use.	Yes	The software tool used for material balance deviation and material balance test should be validated and results should be approved. Records of these activities should be kept.	Check validation reports and records of approval.
	No		
b) Accountancy and measurement method data used for computing the standard deviation of any balance should come under the quality approach for data and its use.	Yes	Data to be used should be traceable. Records changes should under the same approach as any other.	Check the traceability of data and records of corrections.
	No		
c) The algorithms being used to compute standard deviation should be described in a technical document.	Yes	It should be described how material balance deviation is derived from measurement and estimations uncertainties. The document should be under permanent revision in case of changes or improvements.	Check that there is a technical justification to the algorithm for calculating material balance deviation. Check that it is updated in terms of measurement methods and estimations.
	No		

Criteria	Applicability Yes/No	Interpretation	Subjects to be discussed during audit
d) The method should provide balance standard deviations which correctly reflect the pattern of processing during the balance interval and which also correctly reflect the measurement history (or estimation method) of the mass values used to compute the balance.	Yes	Self explicative.	Check that the material balance deviation has been applied to the amount of material corresponding to the right balance period.
	No		
e) Where estimates of in-process material are based on historical information or modeling of some kind, the estimation method and the method of establishing the uncertainty should be described in some technical document.	Yes	The material estimation and its uncertainty should be justified in a document that should be under permanent review.	Check the justification document and records.
	No		
f) The work procedures for balance testing, the software user guide, the software description and the technical method documents should be written so that their completeness and mutual consistency can be recognized.	Yes	All the material balance documentation should be coherent and consistent.	Check consistency, e.g. of uncertainties expressed in technical documents and uncertainties used for computing.
	No		

Establishment of the Role of NMAC Audit in the Context of the Safeguards Cooperation between European Commission and the IAEA

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1. Formal view

The preamble of the 'Commission Recommendation on the implementation of a nuclear material accountancy and control system by operators of nuclear installations' states:

> *"Whereas the Commission working document entitled 'Implementing Euratom Treaty Safeguards' (IETS), contains the requirement that the Commission draw up a reference framework for high-quality nuclear material accountancy and control (NMAC) systems. It also states that auditing of nuclear operators' NMAC systems will be one of the Commission's supervisory activities."*

The Recommendation starts with the statement:

> *"**Section 1 — Purpose and scope***
> *This Recommendation describes the reference characteristics of an operator's NMAC system complying with the legal obligations of Regulation (Euratom) No 302/2005. …"*

If audit is understood in this sense as a supervisory activity of the Commission relating to the compliance of an operator's NMAC with the Euratom Regulation, than an European commission NMAC audit is an activity where the IAEA has no own role. The operator's NMAC system is in no case subject to IAEA's supervision.

This view is also reflected in the implementation arrangements for integrated safeguards on which IAEA and the European Commission have agreed for different types of facilities. These documents describe in detail the purpose and the activities to be performed for each type of inspection (PIV, interim inspection, etc.) when implementing safeguards in the EU countries:

> *"This paper provides a scheme for the implementation of a Partnership Approach (PA) for [facility type], which will allow both the International Atomic Energy Agency (IAEA) and EURATOM to fulfil their respective obligations under INFCIRC/193 and INFCIRC/193/Add.8 and adapted to reflect the IAEA's integrated safeguards and the European Commission's (the Commission) strategy for improved safeguards effectiveness."*

The term "audit" is not explicitly mentioned in these PA papers. Here, audit is not seen as an activity to be carried out jointly.

If, on the other hand, NMAC audit activities are performed with a specific scope (targeted audits) like tracing of anomalies, checking inventory control procedures or a thorough design information verification, the IAEA could participate as far as the activities are covered by the mandate given through the safeguards agreements. This was the case in the past and there is no reason why this would not be continued.

The different PA paper states:

> *Design information verification will be performed as necessary…*

For those activities the IAEA has a clear mandate although they are not called "audits" in the partnership agreement.

Compared to the European commission, the IAEA has for a full NMAC audit a much weaker legal basis and no enforcement capabilities:

- The Community is the owner of all nuclear material within the community (Article 86 of the Euratom Treaty: *"Special fissile materials shall be the property of the Community. …"*). Member States, persons or undertakings have the unlimited right of use and consumption of the special fissile material. The IAEA has no property or possession rights on the nuclear material under their safeguards.
- The Commission monitors that nuclear material is used as declared. (Article 77 of the Euratom Treaty: *"…the Commission shall satisfy itself that, in the territories of Member States: …ores, source materials and special fissile materials are not diverted from their intended uses as declared by the users; …*). The task of the IAEA is to apply safeguards *"…for the exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices".* (Article 2 of INFCIRC/193). As long as nuclear material is not misused for military purposes, the use of the material is not a matter of IAEA safeguards.
- The European Commission has a very broad right of access (Article 81 of the Euratom Treaty: *"…On presentation of a document establishing their authority, inspectors shall at all times have access to all places and data and to all persons who, by reason of their occupation,*

deal with materials, equipment or installations subject to the safeguards. …"). Even the Additional Protocol provides the IAEA with much more narrow access rights.

- The European Commission has a broad range of enforcement capabilities as laid down in Article 83 of the Euratom Treaty:
- *1. In the event of an infringement on the part of persons or undertakings of the obligations imposed on them by this Chapter, the Commission may impose sanctions on such persons or undertakings. These sanctions shall be in order of severity:*
  - *a. a warning;*
  - *b. the withdrawal of special benefits such as financial or technical assistance;*
  - *c. the placing of the undertaking for a period not exceeding four months under the administration of a person or board appointed by common accord of the Commission and the State having jurisdiction over the undertaking;*
  - *d. total or partial withdrawal of source materials or special fissile materials.*

  These rights were exercised by the European Commission in a number of cases. The IAEA enforcement capabilities are restricted to carry forward their findings and concerns to the Board of Governors.

In contrary to the IAEA who deals with the State, the European Commission has direct access and enforcement rights on the operators. So, the legal basis for enforcement measures is much stronger for the European Commission.

The IAEA cannot trigger an audit, has no original legal ground to request access to documents, information and people to the same extent as the European Commission inspectors can do. In conducting or even only participating in such an audit, the IAEA is depending on the consent of the state and operator concerned. This limits the value of a NMAC audit for the IAEA as a routine safeguards tool as it is intended for Euratom Treaty safeguards.

Targeted audits with a limited scope (although not called 'audits' in the past), however, are since long safeguards practice, e.g. during design information verification or discrepancy/anomaly follow-up activities.

2. Can European Commission NMAC audit activities and results be of value to the IAEA?

Although the IAEA does not currently perform safeguards audits, it has a large experience with different kind of reviews, for example:

- OSART – Operational Safety Review Team. Under this programme, international teams of experts conduct in-depth reviews of operational safety performance at a nuclear power plant.
- SCART – Safety Culture Assessment Review Team. The overall aim of Safety Culture Assessment Review Team (SCART) missions is to provide advice and assistance to Member States in the form of an in-depth independent review of safety culture at a Member State nuclear facility, to enhance the safety culture of the nuclear facility.
- IRRS – Integrated Regulatory Review Service. It is the objective of the IRRS mission to review the regulatory supervision against comparison with IAEA safety standards and where appropriate, good practices in other countries.
- ISSAS – The IAEA International SSAC Advisory Service. To assist in strengthening their SSACs, the Agency has provided direct assistance to Member States including technical advice, training and other guidance at both the State and facility levels.

The Agency knows from these services the deep degree of insight the reviewer gains into the internal structures of the reviewed. Similar deep insights will also be gained from audits and can contribute to the safeguards goals.

One of the main ideas to apply Integrated Safeguards is the transition from a facility oriented safeguards approach to a state level approach. The state level approach is based on a state evaluation which is defined in the IAEA Safeguards Glossary as follows:

> ***12.20. Safeguards State evaluation*** *— a continuous process of evaluating all information available to the IAEA about a State's nuclear programme and related activities for the purposes of planning safeguards activities in the State and of drawing conclusions about the non-diversion of nuclear material placed under safeguards and about the absence of undeclared nuclear material and activities in the State (see No. 12.25). Evaluation is performed in three stages.*

With a view to that state evaluation one could expect that the IAEA welcomes all information made accessible to it. Participating in a NMAC audit (even if only as an observer) would allow the IAEA to build up deep insight knowledge for the state under evaluation in several respects:

- Insight into the working of the audited operator's NMAC and the respective national nuclear related environment (national legislation, licensing procedures, supervision, etc.).
- Insight into working aspects of the auditing authority, in this case European Commission.

IAEA participation as an observer in audit activities that are beyond the scope of inspections could be carried out as a visit. The IAEA Safeguards Glossary explains:

> ***VISITS AND INSPECTIONS***
>
> ***11.1. Visit*** *— the presence of IAEA inspectors at a facility for purposes other than a safeguards inspection (see No. 11.2) or complementary access (see No. 11.25); examples of such purposes are the examination and verification of design information on a facility (see Nos 3.29 and 3.30), fact finding and technical discussions in connection with the development of safeguards approaches (see No. 3.1), and negotiations and discussions with facility and State authorities regarding safeguards implementation matters. Visits are not counted as person-days of inspection (see No. 11.20).*

The problem with this kind of information is that its contribution to the safeguards conclusion for a state is difficult to quantify. It is impossible to quantify an immediate payoff if the IAEA participates in such an audit. Participation in audits would also be a purely Euratom-specific measure not applicable to states outside the EU.

Present IAEA Integrated Safeguards is a first step to a more holistic view to the states under consideration. The potential of that state level view seems not yet fully exploited. From the outside, it is hard to see that integrated safeguards approaches and safeguards effort spent in the field are varying due to different levels of assurances gained from the individual state level evaluations.

The answer to the question whether participation of IAEA in European Commission NMAC audit would be of value to the IAEA is a clear YES. The information and knowledge gained could greatly enhance the process of IAEA state evaluation.

Besides the contribution to the state evaluation, the possibility to participate in an audit could also be seen as a good example for confidence measures and increased transparency. Besides that, it could also be an excellent training opportunity for IAEA inspectors.

The question here is, what value does the IAEA really assign to such ‘soft’ factors and information in their safeguards approaches?

Final Report of the ESARDA NMAC Audit Group

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1. Introductory remarks

It seems to be a normal event that the introduction of new techniques and methods are mostly accompanied with some kind of uneasiness. There is always the question whether the new tool is adequate and whether it is factually improving or increasing efficiency of the presently applied practice. In the case of auditing in the context of NMAC matters the problem was aggravated by the lack of a clear definition of the term “audit” and its scope. The preceding ESARDA NMAC Audit Focus Working Group compiled three documents that have been published in the ESARDA Bulletin Issue 37 [1]. The Group stated that an ISO approach to auditing is generally applicable to NMAC systems and set up a model of good practice for NMAC that could serve as audit criteria as well as a guideline to conduct audits in a structured way based in the current internationally accepted best practices.

It is unprecedented and remarkable that the European Commission announced in official documents *(Commission Staff working Document [SEC(2007)293 on the principles and modalities of the implementation of the European Commission’s nuclear safeguards tasks ‘Implementing Euratom Treaty Safeguards’ (IETS [2]))* to take into account the expertise of the ESARDA NMACAF (NMAC Audit Focus) WG recommendations for producing a model of NMAC system prior to practically implement NMAC audits as a safeguards tool. As a consequence, the Commission Recommendation of 11 February 2009 (2009/120/Euratom) on the implementation of a nuclear material accountancy and control system by operators of nuclear installations [3] was issued on basis of the output of the NMACAF WG. Prior to its issuance the document has been widely consulted with Member States and via the respective Member States with operators also. It was the prime task of the new ESARDA NMAC Audit Working Group to check whether the criteria expressed in the Commission Recommendation of 11 February 2009 (2009/120/Euratom) [3] are applicable under real operating conditions in different facility types. Since the audit issue still contains conflicting views partially a resumption of the general discussion within the preceding NMACAF WG was unavoidable, but helpful and greatly contributed to the outcome of the new NMAC Audit Working Group that has commenced its work early 2009.

2. Basis of work

In the context of the document “A new framework for Euratom safeguards” [4] the Working Party on Atomic Questions (WPAQ) identified three main pillars supporting the assurance of non-diversion of nuclear materials from their declared uses:

- the operator implementing an effective nuclear material accounting and control (NMAC) system;
- timely reports by the operator relating to the installations as well as of the location and quantity of nuclear material; and
- independent verification by the Commission of these reports and of the effectiveness of the operator’s NMAC system.

After sound analysis of the NMAC audit usefulness and efficiency, and after having taken the necessary experience in the matter, the European Commission has identified four cases where conducting NMAC audits could serve as an efficient safeguards tool:

- to assess the measurement systems of bulk handling nuclear facilities;
- when a shortfall has been found in the operator’s NMAC system;
- for installations joining the Euratom safeguards regime;
- for installations where the physical verification can be carried out only in a limited way.

A successful audit and a correct implementation of the audit’s outcome may result in a reduction of inspection frequency or effort.

Since the issuance of the document “A new framework for Euratom safeguards” [4] in December 2005 some developments that may influence the WG task have been taken into account:

- Based on the outputs of the NMAC AF WG, a model of good practices for an operators’ NMAC system has been derived, leading to the Commission Recommendation (2009/120/Euratom) [3].

- Trial audits have been carried out by the Commission in France, in the UK, in Spain, in Germany. The experience gained definitely contributed to the performance of a number of NMAC audits that have been carried out afterwards.
- Integrated Safeguards have been progressively implemented in the NNWS EU Member States and are applicable since 01.01.2010.

3. NMAC audits versus safeguards inspections

According to the current European Commission policy, audits beyond the four situations mentioned above are carried out only on a voluntary basis. This is preferably the case if they lead to a win/win situation.

This means, they must offer an advantage to both parties, to the Commission as well as to the operator. As mentioned before the win/win-approach is not necessarily required if audits are caused by irregularities and where audits pose an appropriate tool to resolve anomalies.

Audit reports are addressed directly to the operator's management and might have an impact on its NMAC system.

It is common sense that audits need careful preparation and constitute generally more burden on both sides than regular inspections. A win/win situation is, therefore, guaranteed only if the effort is compensated by something else.

Generally, the audit principle offers the chance to evaluate the accounting system as a whole instead of verifying a number of single NMAC system components (product audits) like records, analytical measurements, instruments or other individual items. The potential of a win/win-situation is only given if system audits make product audits obsolete and if a system audit requires less effort as the totality of product audits. If system-audits do not reduce or replace product-audits, a win/win-situation is not given.

There is no doubt that the audit principle can contribute to the continuous improvement of the operators' NMAC system. However, by taking into account the expected benefits, there is a need to identify situations where performing an audit is appropriate for and those where it is not.

Situations where audits are considered appropriate:

- Restoring confidence/informing the Commission: if, due to missing knowledge of the industrial and/or commercial constraints of a nuclear facility, conclusions of the inspections can lead to misinterpretations. In such cases, appropriate solutions must be found to solve the problems in a spirit of transparency taking into account the interests of both, the operator and the Commission.
- Improving confidence: auditing is adequate when it has the potential to improve the confidence and consequently leads to a reduction of the inspection effort.
- Resolving anomalies.
- For facilities of countries which are newly joining the European Union, as a first assessment.
- On request of the operator in order to help him identifying potential weakness in his NMAC system or to receive expert advice from the Commission.

Situations where audits are not considered to be appropriate (unless NMAC irregularities have occurred):

- In new facilities, if BTC and operator's NMAC system are elaborated and implemented in close cooperation with the Commission.
- In facilities where one inspection per year or less is carried out.
- When there is no need to restore confidence or for additional information for the Commission or where audits will not provide additional information to the Commission compared to that it already has.
- In case audit activities rely mainly on the access to sensitive information (e.g. analytical measurement procedures, uncertainties algorithms). Such situations may appear counter-productive since refusing of access could possibly be interpreted as a lack of transparency of the operator.

4. Evaluation of the practical applicability of the Commission Recommendation (2009/120/Euratom) [3]

NMAC systems differ greatly according to the purpose of nuclear facilities and consequently, on the nature and composition of the nuclear material handled. On the other hand, the high number of facility types would exceed the ability of the Working Group to come to conclusions in a reasonable time if particularities of individual installations are considered in detail. Therefore, the Audit Working Group decided to check the practical application by focusing on three basic facility types, i.e. item facilities, bulk handling facilities and research installations.

To this end, the Working Group derived from the Commission Recommendation (2009/120/Euratom) [3] a number of items that are considered to represent audit criteria. These criteria were assembled in form of a table. The table is composed of 4 columns, the first of which displays the respective criterion. The second column shows whether the criterion in principle applies to the three facility types that have been selected for consideration. In a third column the Working Group tried to interpret the respective criterion in terms of its application and provides clarification to operators about the practices that can be followed in order to comply with that criterion. In a fourth column advice is given to auditors which information could give adequate information on the criteria fulfillment.

Compilation and discussion of the table constitute the main effort of the Working Group and demanded most of its time. It, therefore, represents the backbone of the Working Group´s advice. The main conclusion that can be drawn from the table as well as from the internal discussions is, that all of the criteria forming the essence of the Commission Recommendation (2009/120/Euratom) [3] can be practically taken into account, provided they are applicable to the facility type in general. In particular in pure item facilities where NMAC plays a fundamentally different role than in bulk handling facilities, a good deal of the criteria do not apply.

Besides of that important result, the Working Group felt that additional information resulting from its internal discussion but not contained in the table also forms an essential result of the groups work. It is, therefore, summarized in the following.

Availability of NMAC information

A quick glance at the Criteria List that has been derived from the Commission Recommendation (2009/120/Euratom) [3] shows that nearly all of the quoted NMAC information, if applicable to different facility types, seems to be available in case a sufficiently qualified quality management system has been implemented. This does not represent a real surprise. Commission Regulation (Euratom) No 302/2005 of 8 February 2005 on the application of Euratom safeguards [5] calls for an implementation of an adequate NMAC system. Today nuclear installations are organized meeting highest safety and quality management requirements and is frequently certified according ISO or comparable standards. This includes that NMAC systems are in many cases precisely regulated, documented, regularly checked and that responsibilities are allocated. However, the Commission experience shows that even when the nuclear operator runs a certified quality management system, the NMAC process is not always fully implemented and reviewed. Under the assumption that the authors of the Commission Recommendation (2009/120/Euratom) [3] followed the spirit (and even to some extent the wording) of quality management standards it becomes clear that the List of Criteria barely contains requirements that are not available in an nuclear installation operated under prudent management principles in compliance with quality management standards. This does not, however, exclude that NMAC audits carried out by the European Commission give room for revealing weaknesses of the system with subsequent improvement.

Justification of information submission

Even under consideration of Art. 81 of the Euratom Treaty, availability of NMAC information does not necessarily justify its total submission or even disclosure to auditors. This issue represents one of the major fears or suspiciousness of plant operators. This is in particular true for sensitive information. In fact one can derive a direct connection to safeguards needs. A sound NMAC performance clearly postulates besides safety and licensing needs a profound understanding of safeguards rules together with the willingness for compliance. Lack of staff expertise, weak safety culture, a difficult commercial or economical situation may give raise to concern for an auditor to challenge a flawless NMAC execution. However, such kind of information request can only be restricted to special cases and should not be asked on a routine basis. So far, the question of need and justification of information disclosure has not been given enough consideration and still gives room for further discussion. Trial audits and discussion with European Commission representatives showed that satisfactory agreements were found in all cases to dispel respective concerns.

5. Guidance to NMAC Audit Execution

At least in the initial phase of conducting NMAC audits not all fears and inconsistencies will be eliminated by defining criteria or guidelines. Therefore, success as well as acceptance of audits will mainly depend on mutual appreciation and trust. Both parties, the auditor as well as the installation that is subject to audits, can considerably contribute to make this tool an advantage to both. The following proposals may support this desire.

- Safeguards audits and inspections are considered to represent part of the safeguards regime and, therefore, constitute a precondition for plant operation. Nevertheless, they cause impacts to facility operation by binding staff and resources. This impact can be minimized if auditors are trained, knowledgeable and experienced enough to understand the functioning and particularities of the facility under consideration. This fact has been experienced throughout trial audits and is taken into account by the Commission.
- Complex facilities require more knowledge and, therefore, more time for inspectors to get familiar with the task. The same is true for the operator. He also needs to understand the way of thinking, as well as the needs and strategy of the inspector/auditor. A frequent change of persons on both sides would, therefore, lead to reduced efficiency of audits. Experience shows that audits run more efficiently and with less intrusion if auditors are well informed.
- Auditing can be a very time consuming activity for the Commission as well as for the operator. This was one of the lessons learnt during trial audits. Audits require significant preparatory work and appropriate organisation. As a consequence, audits should be avoided during PIV (Physical Inventory Verification) and other situations where the operator faces exceptional situations or additional burden. For efficient audit preparation Commission and operator should agree on a minimum time of ad-

vance notice. There is no doubt that auditing is less resources consuming if documents, supporting activities and methodology are well prepared and followed.

- Acceptance and efficiency of audits will be increased if audits are well prepared for and organized. Auditors need to give advance notice defining the areas of concern or special interest. Once the system has been audited completely it may makes sense to restrict the scope of the subsequent audits to a small number of items and to allocate remaining items to future audits.
- In case of an information request exceeding the operators' preparedness or ability to answer the auditor is requested to justify the need. If justification is given, it may be explored whether the information required can be derived indirectly or from alternative sources.
- As a confidence building measure the auditor must not only collect information. He should explain whether he was able to draw the conclusion he was looking for or the reason for, if not. Sufficient debriefing after the audit forms basis for the success of future audits. Audit report or a letter containing the audit outcome could confirm the level of conformity with the audit criteria of the operator's NMAC system.

6. Subsidiary comments

Auditing of Waste Facilities

Following a comment from the European Commission about audit performance in waste facilities the Working Group defined two generic cases and summarized its discussion as follows.

There is no difference, regarding the audit treatment between waste treatment facilities with a classical NMAC in place producing ICRs (Inventory Change Reports), MBRs (Material Balance Report) and PILs (Physical Inventory List) in which waste is declared as normal nuclear material, and any other facility with similar features.

For wastes storage facilities with no physical verification, where accountancy is limited to bookkeeping, where no input/output verification is carried out, no balance or PIT/PIV is feasible and, therefore, not necessary. In these types of facilities auditing of the system makes sense and renders all other inspection and verification activities unnecessary.

Updating of Audit Criteria

Taking into account future progress, experience, change of the European Commission's safeguards policy and other developments the list of audit criteria is considered a dynamic document. The Working Group proposes the document to be updated and modified by ESARDA as often as necessary. The document is intended to outline the experience of parties, the auditor as well as the installation that is subject to audits. Practical experience with auditing of operators NMAC systems may lead to course corrections regarding the methods how to evaluate the quality of NMAC systems and/ or to adapt the measures for assessing their effectiveness. Sometimes it is essential to consider the developmental history of an individual NMAC system by keeping track of reasons and boundary conditions leading to the presently applied techniques and measures before replacing them by new ones.

The document may evolve through updates and be expanded as needed thereby reflecting the feedback and needs of operators and auditor. However, a review should take place only in case of good reasons, e.g. if:

- additional comments and examples are helpful to better explain the audit criteria;
- it can be demonstrated that alternative approaches produce the same quality level of the NMAC system with less effort;
- the legal basis or policy have changed;
- technical boundary conditions have changed.

7. Concluding remarks

The extensive discussion within the working group lead to the commonly agreed result that the Commission Recommendation (2009/120/Euratom) [3] forms a good basis for the evaluation of NMAC Systems. However, most of the controversial discussion could have been avoided if there was a generic document issued by the European Commission explaining the doctrine of auditing as a safeguards measure. In this document a clear and unambiguous description of the European Commission definition of the term "audit" and its classification towards "inspection" would greatly assist a better understanding and would possibly avoid repeated discussion. Experience gained so far showed that disclosure of sensitive information does not constitute a major concern. In order to eliminate this issue completely it is proposed to provide the European nuclear operators with a self-assessment questionnaire. This would enable the operator to identify sensitive information and to elaborate alternative ways of information without reducing transparency or creating suspicion.

The potential of audits to improve or optimize the NMAC system of nuclear operators by taking advantage of external experience and expert advice is beyond dispute. Therefore, parties, the European Commission as well as the operators would be well advised to take advantage of that tool by carrying out future audits impartially and in mutual trust and confidence. ESARDA experts offer their assistance and cooperation also in future if desired by the parties.

References

[1] Esarda Bulletin No 37. December 2007.

[2] Commission Staff working Document [SEC(2007)293 on the principles and modalities of the implementation of the European Commission's nuclear safeguards tasks 'Implementing Euratom Treaty Safeguards' (IETS).

[3] Commission Recommendation of 11 February 2009 (2009/120/Euratom) on the implementation of a nuclear material accountancy and control system by operators of nuclear installations.

[4] Council documents ST 13895/2/05 REV 2. "A new framework for Euratom safeguards".

[5] Commission Regulation (Euratom) No 302/2005 of 8 February 2005 on the application of Euratom safeguards.

Best student essay from the 6th ESARDA course on Nuclear Safeguards and Non Proliferation

Destructive Analysis: Effective Analytical Support to Nuclear Safeguards and Non-Proliferation

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Abstract

Nuclear safeguards are measures to verify that states comply with their international obligations (Non-Proliferation Treaty and Euratom Treaty) to refrain from using nuclear materials for the development of nuclear weapons, but using it solely in the peaceful civil nuclear fuel cycle...

Destructive Analyses (DA) of nuclear material and of environmental samples collected inside and in the vicinity of nuclear facilities are a key strategy among other complementary measures applied in nuclear material accountancy, control and verification. A great variety of analytical methods is used in order obtain the desired information from a given sample. The chosen method must be applicable to meet the requirements pre-defined by nuclear safeguards. Analytical methods for DA of bulk samples of nuclear material as well as for the assay of single particles found on swipe samples are presented in this paper. Furthermore the drawbacks and benefits of DA for nuclear safeguard purposes are discussed along with considerations concerning the choice of the appropriate analytical method, including the use of quality control tools.

Keywords: destructive analysis; nuclear material; safeguards; bulk sample; environmental sample.

1. Introduction

The main task of nuclear safeguards is the timely detection of a diversion of nuclear material from declared nuclear facilities, the timely detection of misuse of a declared nuclear plant for non-peaceful purposes, and the detection of undeclared nuclear materials and activities. Nuclear activities are proliferation sensitive if they can lead to weapon-usable material, namely plutonium and highly enriched uranium. Nuclear safeguards under comprehensive safeguards agreements (CSA) of the Non-Proliferation Treaty (NPT) cover, therefore, conversion, enrichment and fuel fabrication facilities as well as reactors, critical assemblies, spent fuel storage facilities and reprocessing plants. The Additional Protocol (AP) of the Non-Proliferation Treaty extends the safeguards coverage also to uranium ore mines, uranium ore concentration facilities and heavy water production. Nuclear facilities within the EU are safeguarded by the nuclear safeguard inspectors of both IAEA and Euratom. The IAEA inspectors operate according to the comprehensive safeguards agreements of the NPT while Euratom inspectors operate according to the Euratom Treaty. Euratom and IAEA inspectors cooperate, for instance, in the use of equipment, research and development and have joint team inspections. Nuclear plant designers must consider safeguards at an early design stage and make provisions that the facility can be effectively safeguarded. In addition to providing design and process flow information, the operator must keep complete and coherent accounting records and report any changes on the inventory i.e., for shipments, receipts, processing and storage. Inspectors verify operator's declarations via independent measurements applying destructive (DA) and non destructive (NDA) methods as well as by placing safeguards monitoring, surveillance and seals systems. A proper implemented inspection scheme needs to meet the three safeguards goals of "significant quantity", "timeliness of detection" and "detection probability". They determine the number of items to be verified. The common basis for safeguards system design under the NPT and the Euratom Treaty is to choose the number of items to be verified in such a way that the targeted probabilities for risk of 'false alarm' and 'non detection' of a diversion of a defined quantity of nuclear material within characteristic time are met: for example ensuring the detection of removal of 8 kg plutonium within one month with a detection probability of 95%. The three safeguards goals are defined in similar ways by both Euratom Treaty and NPT. Key materials such as spent fuel solutions, plutonium nitrate, plutonium oxide, uranylnitrate, uranium oxide, mixed (plutonium and uranium) oxide (MOX) and uranylhexafluoride are routinely sampled for destructive bulk analysis according to the nuclear inspection scheme.

Up to the early 90s only the declarations made by the operator of the nuclear facility could be verified for their correctness in compliance with the NPT. Assurance of the absence of undeclared nuclear material (completeness) was not part of the safeguards authorities' mandate. Triggered by the discovery of the clandestine nuclear weapons programme of Iraq in 1991 and first appearances of the new phenomenon of illicit trafficking of nuclear material in the 1990s, the Additional Protocol of the NPT was approved by the IAEA's Board of Governors in May 1997. It enabled among other improvements complementary access for IAEA inspectors to all installations of the nuclear fuel cycle including mines and concentration plants, as well as to related research and development facilities, even on short notice. Methods for remote sampling of gases to detect uranium enrichment and plutonium separation facilities are still under development while destructive analysis of environmental swipe samples is already part of the routine safeguards protocol. Particularly, data obtained by single particle analysis from swipe samples are a powerful safeguards tool providing information on history and origin of the nuclear material [1].

Destructive analysis (DA) is a key tool for safeguards in addition to surveillance, seals and non-destructive analysis (NDA). DA is defined as measurements introducing a significant change to the batch of material: The sample aliquot taken from the batch for measurement is subsequently not returned to the batch. DA is applied when accurate measurement results with small measurement uncertainties are required. The performance of the analytical methods applied has to provide analytical measurement results that meet the International Target Values for Measurement Uncertainties in Safeguarding Nuclear Materials [2]. Safeguards laboratories can be located and operated on-site or samples can be sent for analysis to qualified off-site laboratories. In the field of nuclear material and environmental destructive sample analysis safeguards authorities work with a network of analytical laboratories to check correctness and completeness of declarations. Physical verification measurements of fissile material are carried out at the on-site laboratories at the European reprocessing plants in La Hague (F) and Sellafield (UK). Furthermore DA is the strategy of choice for special samples in terms of isotope composition, sample matrix or concentration and for non-routine analysis such as nuclear forensic investigations.

2. Routine bulk samples

In order to check the correctness and completeness of the declarations made by the operator concerning the facility's material balance, representative aliquots of plutonium and/or uranium containing material are taken by the safeguards inspectors. These samples are called bulk samples. The quantitative content of plutonium and/or uranium as well as their isotopic composition (enrichment) is of safeguard's interest [3]. Some techniques such as K-edge densitometry (KED) and X-ray fluorescence (XRF) can be applied for destructive as well as in non-destructive analysis depending on whether the sample is returned to the batch after analysis or not [4].

2.1. Frequently applied DA techniques for elemental assay in bulk samples

2.1.1. Isotope Dilution Mass Spectrometry

Isotope dilution mass spectrometry (IDMS) is based on the addition of a known amount of a "spike" to a known amount of the dissolved sample. This "spike" is an enriched isotope solution; its addition to the sample solution leads to a change in the isotope ratio [5]. The isotope ratios in the spiked sample solution and the un-spiked sample solution are measured by mass spectrometry while the isotopic composition of the spike can be obtained form the reference material certificate [6]. In case of absence of the isotope used for spiking in the un-spiked sample a separate measurement of the un-spiked sample is not necessary [7]. The elemental concentration in the sample can be calculated using the known (weighed) amounts of sample and spike as well as the isotopic compositions mentioned above. ^{242}Pu, ^{244}Pu, ^{239}Pu, ^{240}Pu are often used as spikes for plutonium assays [5] while for IDMS measurements of Uranium mainly ^{233}U and to a smaller extend ^{235}U and ^{236}U are used as spikes [7]. The mass spectrometric method routinely used for the measurement of the isotope ratios is thermal ionization mass spectrometry (TIMS) as applied in the laboratory shown in Figure 1. Recently laboratories applying multi collector inductively coupled plasma mass spectrometry (MC-ICP-MS) have demonstrated via participation in interlaboratory comparisons that their measurement performance is comparable to TIMS [8]. Depending on the mass spectrometric measurement technique, e.g. total evaporation, and on the certified spike isotopic reference material used, relative expanded uncertainties for IDMS in the range of 0.025% to 0.1% can be achieved [9-11].

2.1.2. X-Ray Fluorescence

X-ray fluorescence (XRF) is used to measure the elemental concentrations of plutonium and uranium of solutions [4]. In order to generate fluorescent X-rays in the sample matrix, the sample is irradiated with X-rays emitted from an X-ray tube or radioactive source. The X-rays subsequently emitted by the sample are detected [13]. Either ratios of uranium and plutonium such as Pu/Pu+U [14] or absolute concentrations of plutonium and uranium are measured. The latter requires instrument calibration with suitable standards. Relative expanded measurement uncertainties

Figure 1: Nuclear mass spectrometry laboratory at IRMM (picture courtesy of IRMM) [12].

of about 0.5% have been demonstrated [7]. XRF is also applied (in combination with hybrid K-edge densitometry) for the measurement of solutions in the reprocessing facility in La Hague [4]. Additionally, XRF has also shown potential for the determination of metal impurities in nuclear materials such as U_3O_8 [15].

2.1.3. Titration

The concentrations of plutonium and uranium can also be determined by titration.

The Davies and Gray potentiometric titration method is the most widely used titration method for uranium [16]. U(IV) is titrated with potassium dichromate after reduction of U(VI) to U(IV). The reduction step is necessary because uranium is mostly present as U(VI) in nitric acid sample solutions. This method is widely used by plant operators as well as in safeguards analytical laboratories. Both Davies and Gray titration and isotope dilution mass spectrometry methods have comparable levels of accuracy for the determination of pure uranium materials. Higher uncertainties must be expected for mixed oxides containing uranium and plutonium [17].

Plutonium can also be determined by potentiometric titration. First the plutonium is oxidised to Pu(VI) with argentic oxide in nitric acid solution; the excess of the argentic oxide is removed with sulphamic acid. Then a weighed amount of Fe(II) is added. Fe (II) subsequently reacts with Pu(VI). The excess of Fe (II) then is titrated potentiometrically with a standard potassium dichromate solution. This method can also be applied to nitrate solutions containing a large amount of uranium. The coefficient of variation is usually better than 0.2% [18].

2.1.4. K-Edge Densitometry

K-edge densitometry (KED) is suitable for the determination of uranium and plutonium concentrations in solutions. When both elements are present in the same sample solution, however, the K-edge densitometry measurement should be combined with K-edge X-ray fluorescence densitometry (K-XRF) in order to take interferences caused by K-absorption edges in the same energy region into account.

For a KED measurement the sample solution is transferred in a vessel with defined path length and passed through by a highly collimated X-ray beam. The x-ray transmission is measured as a function of energy in critical energy regions (K-edges). Volume concentrations from 25 g/L to approximately 400 g/L of uranium or plutonium can be obtained using calibration curves. In order to transform the measured volume concentrations (g/L) to mass concentrations (g/g) the density of the sample solution must be known [7]. An example for K-edge densitometry in fuel material can be viewed in [19].

2.1.5. Gravimetric assay

Gravimetric assays of plutonium or uranium are primary measurement methods with high precision and accuracy. The weighing form of uranium for the assay is U_3O_8, produced by ignition of uranyl nitrate at about 1000°C. The applied ignition temperature and elemental impurities such as calcium and phosphorus can lead to deviations of the stoichiometry of U_3O_8 due to formation of complexes such as uranates. These effects must be considered. Impurities can for instance be measured by GD-MS, SS-MS or ICP-MS [7]. A gravimetric determination of uranium in uranyl nitrate is described in [20]. There are also gravimetric methods for the determination of plutonium such as ISO method ISO 8425:1987 for the determination of plutonium in pure plutonium nitrate solutions.

2.2. Less frequently applied DA techniques for elemental assay in bulk samples

2.2.1. Spectrophotometry

Plutonium and uranium concentrations can also be determined by spectrophotometric methods. Although these methods are rarely used for nuclear safeguards applications, they are simple and fast measurement methods in process control such as the spectrophotometric determination of uranium in process streams [21]. The spectrophotometer measures the absorbance of light that passes through the sample: A monochromator ensures that the light has the desired wavelength or a very narrow range of wavelengths. The light that leaves the monochromator passes through the sample solution which is placed in a cuvette with defined length. The absorbance of the light is a function of the concentration in the sample solution [22]. Such a spectrophotometric technique can also be used for the assay of plutonium concentrations after solvent extraction [23].

2.2.2. Coulometry

Coulometry is not frequently applied for routine verification measurements in nuclear safeguards despite its potential to provide precise and accurate measurement results [7]. A current is applied to the sample solution triggering oxidation or reduction of the analyte (uranium or plutonium) to another valence state. When all of the analyte is transformed a shift in the potential of the working electrode can be observed marking the endpoint of the titration. The magnitude of the current and the titration time are used to determine the amount of the analyte in the sample solution. Given that the volume of the sample solution is known the concentration can be determined [24]. A method for a coulometric plutonium assay is described in [25]: Pu(VI) is reduced to Pu(IV) with help of a ferrous mediator. This method has a precision better than 0.1% for 5 mg and 1.2% for 0.1 mg plutonium. [26] describes the determination of uranium by constant current coulometry based on a modified version of the titration method by Davis and Gray [16]. Measurement results with relative standard uncertainties of 0.1% can be obtained by coulometry.

2.3. Isotope assay in bulk samples

2.3.1. Thermal Ionization Mass Spectrometry

Thermal Ionization Mass Spectrometry (TIMS) is the most commonly used tool for nuclear safeguards to obtain precise, isotope ratio measurement results of uranium and plutonium. It is also applied, in combination with the correct use of certified reference materials, in isotope dilution assays for the accurate determination of plutonium and uranium concentrations. A mass spectrum of natural uranium is show in Figure 2.

Micro-gram to nano-gram quantities of the analyte are loaded as oxides or in aqueous chloride or nitrate solutions on a filament (small metal ribbon). In case of liquid samples an electric current is applied to the filament in order to accelerate the drying process of the sample solution on the filament [27]. Prior to transferring the sample to the filament, the filaments are degassed in order to evaporate contaminants from the surface of the filaments [28]. Additionally, filaments can be carburized prior to sample loading. As a consequence of the formation of plutonium or uranium carbides a larger portion of +1 charged ions and less oxide species of the analyte are formed, leading to more intense and stable ion beams [29]. The carburisation technique is used for environmental samples where the analyte is only present in the pico-gram range [28].

During the measurement the sample is heated to >1600°C in vacuum and thereby vaporized and partially ionized. The resulting ion beam is focused by ion optics and split into beams with specific mass to charge ratios in a magnetic sector. The ion beams are measured one after another in case of a single detector instrument in so called peak-jumping mode. In case of a multi-collector instrument several ion beams are measured simultaneously [27]. In order to decrease the total measurement uncertainty the "total evaporation method" can be applied. It combines the complete evaporation of the sample with multiple ion collection: the entire sample is evaporated and ionised in order to eliminate measurement bias caused by an increased amount of lighter ions produced in the beginning of the measurement as well as an increased amount of heavy ions in the end of the measurement. Traditional TIMS methods provide for example isotope amount ratios with relative expanded uncertainties of 0.11–0.14% for samples with 0.50–20.0 mass % of ^{235}U, while the total evaporation method lowers uncertainties to 0.039–0.077% for the same type of samples [30]. The development of the "modified total evaporation" has recently significantly improved the measurement performance particularly for the minor abundant isotopes [31, 32].

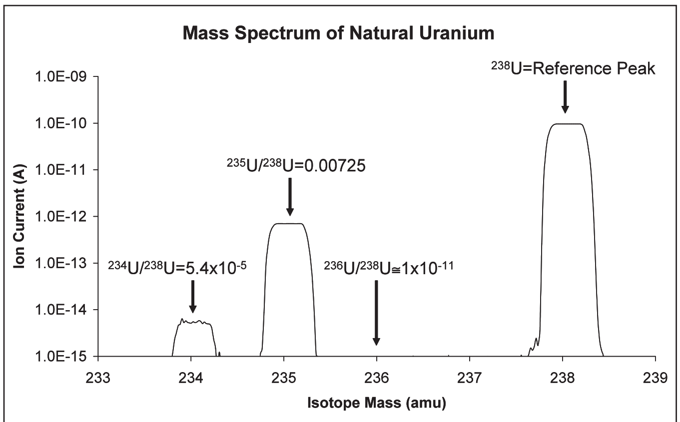

Figure 2: Mass Spectrum of Natural Uranium [33].

2.3.2. Gas Source Mass Spectrometry

Gas source mass spectrometry is mostly applied in enrichment plants. This technique is only occasionally used for nuclear safeguards due to the fact that this type of mass spectrometer can exclusively measure uranium hexafluoride (UF6) samples. The enrichment of uranium hexafluoride is measured directly after ionisation by electron impact. The resulting ions pass a magnetic sector field before they are detected with a similar detection system as described for TIMS. Prior to the measurement, volatile compounds such as HF (hydrofluoric acid) must be removed. Milligrams amounts of UF6 are required and the sample throughput is low since the measurement procedure usually requires the use of two certified isotopic reference materials per sample in order to minimize effects such as drifts, non-linearity and memory effects. Isotope ratios with relative standard deviations as low as 0.012% can be obtained [34].

2.3.3. Alpha-Spectrometry

Alpha spectrometry is a useful technique for the determination of alpha-particle emitting radionuclides in environmental and nuclear fuel samples. A major drawback of this technique is the extensive sample preparation such as electro disposition after anion exchange purification in order to produce thin sample layers and remove interfering elements [35]. Since the resolution of commercially available silicium detectors is not sufficient for quantitative analysis of actinides (such as ^{240}Pu, ^{239}Pu, ^{238}Pu, ^{241}Am, ^{233}U, ^{234}U and ^{232}U), complex and highly sophisticated computer algorithms need to be used to obtain isotope ratios such as $^{240}Pu/^{239}Pu$. Alternatively, high resolution alpha spectrometers can be used. The uncertainties for the determination of $^{240}Pu/^{239}Pu$ with high resolution alpha-particle spectrometers are in the range of 0.4-1.6% [36].

2.4. Combined methods

There are also methods combining different measurement techniques and principles in order to obtain more information about the sample. Two combined methods are discussed below.

2.4.1. COMPUCEA

COMPUCEA stands for Combined Procedure for Uranium Concentration and Enrichment Assay. This compact and transportable system allows high-accuracy uranium elemental assay and enrichment determination for uranium oxide powders and pellets from enrichment plants. Consequently transport of radioactive material can be avoided since COMPUCEA be used on-site. The sample is dissolved in nitric acid and the sample solution is subsequently measured using L-edge densitometry and passive gamma counting to obtain the uranium concentration and the ^{235}U enrichment. COMPUCEA is routinely used for inventory verification at European LEU (low-enriched uranium) fuel fabrication plants [37].

2.4.2. Hybrid K-Edge/K-XRF Densitometry

Hybrid K-edge/K-XRF densitometry (HKED) is a combination of K-edge densitometry (KED) and X-ray fluorescence (XRF) measurements (Figure 3). It constitutes an accurate and reliable method for the determination of the concentrations of uranium and plutonium in sample solutions. HKED is thus often used for nuclear material accountancy verification in reprocessing plants.

An X-ray generator produces an energy spectrum of bremsstrahlung photons which are directed through a vial containing the sample. This X-ray beam passes through the sample vial of well-defined path-length to a detector that measures a transmission spectrum using the absorption edges for the concentration determination. An X-ray fluorescence detector is placed at a backward angle of typically 150° relative to the X-ray beam. Concentrations lower than 50 g/L are covered by the XRF measurement while KED covers higher concentrations. Combining these two techniques allows with proper instrument calibration concentration measurements of uranium and plutonium

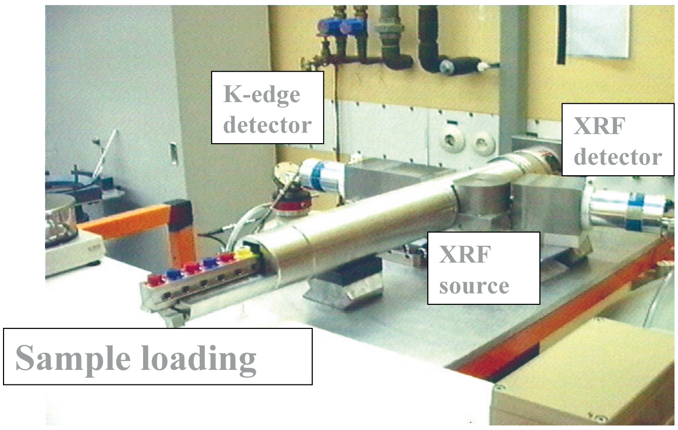

Figure 3: Hybrid K-Edge/K-XRF Densitometer (picture courtesy of ITU) [38].

with a combined relative uncertainty of <1% at concentration levels above 0.5 g/L [4].

3. Environmental and swipe samples

Environmental sampling has become a vital tool of treaty verification since the legal basis for environmental sampling in nuclear safeguards was enhanced by the Additional Protocol (1997) complementing the Non-Proliferation Treaty (1968). Provisions for both location specific and wide-area environmental sampling are included in the Additional Protocol [39].

Most environmental samples subject to destructive analysis are so called “swipe samples” taken at nuclear facilities such as enrichment plants as well as at locations suspected of undeclared nuclear activities. Dust is taken up with a cotton cloth by swiping surfaces. Particles and aerosols are often released when nuclear material is manipulated. Theses particles can thus be found in many locations in and possibly around a nuclear facility. They “carry” an isotopic fingerprint related to the processes in the installation and the source of the material Swipe samples taken at a facility that has been operated over a long period can potentially provide additional information about equipment, plant design, operational parameters and the history of the facility, because it is difficult to clean up and remove released particles [40]. The analysis of environmental samples for nuclear safeguard purposes can be divided in bulk and particle analysis. The result of a bulk analysis applying similar methods as previously described for bulk analysis of nuclear material samples is the average isotopic composition of all particles sampled with the cotton cloth. Single particle analysis involves the measurement of singular individual particles containing for instance sub-pg to pg amounts of uranium [41, 40].

3.1. Single particle analysis

3.1.1. Secondary Ion Mass Spectrometry (SIMS)

Single particle analysis can help to verify the completeness of records and to unveil undeclared nuclear activities. One of the most important methods for the measurement of isotopic ratios of single uranium containing particles (Figure 4) is Secondary Ion Mass Spectrometry (SIMS) [40]. Prior to the measurement the particles are deposited on carbon disks by liquid phase extraction or vacuum impaction. In order to produce secondary ions originating from the sample surface a primary ion beam is focused on the sample. The secondary ions are separated according to their mass to charge ratio in a sector field mass spectrometer using a combination of an electrostatic analyzer and a magnetic analyzer [42].

A major drawback of SIMS using Small Geometry SIMS instruments (SG SIMS) are isobaric interferences reducing the accuracy of the measurement especially when ratios of minor uranium isotope are measured, i.e. $^{236}U/^{235}U$ and $^{234}U/^{235}U$. Large Geometry SIMS instruments (LG SIMS) provide higher mass resolution and ion transmission. Both LG SIMS and SG SIMS instruments are based on double focusing mass spectrometers, but LG SIMS uses a magnetic sector with a larger radius. SIMS measurements can be automated using ion imaging for fast screening in order to locate single particles and for measuring the enrichment of these particles. Thus particles of interest can be located among large numbers of other particles (Figure 5). The main limitations of LG-SIMS compared to TIMS are the necessary hydrogen correction for ^{236}U [40] and difficulties in measuring plutonium isotopes due to isobaric interferences from ^{238}UH on ^{239}Pu and from ^{241}Am on ^{241}Pu [41].

3.1.2. Fission Track Thermal Ionization Mass Spectrometry

Fission track thermal ionization mass spectrometry (FT TIMS) is routinely used in nuclear safeguards for the analysis of single uranium containing particles: The particles from a swipe sample are deposited onto one or between two polycarbonate films serving as fission track detector [44, 45]. The particle baring film is irradiated by thermal neutrons in a nuclear reactor. With increased neutron flow, the detection limit can be lowered. Single particles containing fissile isotopes such as ^{235}U or ^{239}Pu are located by their fission track clusters on the polycarbonate film under an optical microscope. Each located single particle is then transferred to a filament for isotopic TIMS analysis using a micro manipulator [44]. A major disadvantage of FT TIMS compared to SIMS is the time consumed till measurement results are obtained and the need for a reactor for neutron activation; thus FT TIMS requires more laboratory resources. On the other hand TIMS does not require hydrogen correction for ^{236}U [40].

3.1.3. SEM-EDX/TIMS

SEM-EDX/TIMS stands for a technique for analysis of single uranium and plutonium particles combining scanning electron microscopy (SEM) with energy dispersive X-ray spectrometry (EDX) and thermal ionization mass spectrometer (TIMS). Uranium containing reference particles are shown in Figure 4.

The sample particles are first transferred to a graphite planchet using a vacuum impactor prior to applying the SEM-EDX/TIMS technique. The particles can be fixed on the graphite by organic coating that is subsequently removed by evaporation as described in [41]: The particles deposited on the carbon planchet are analysed with an EDX spectrometer attached to an SEM in order to find uranium or plutonium containing particles of interest . These particles are one by one picked-up using a micro-manipulator in the sample chamber of the SEM. Each particle can then be directly transferred to a filament for TIMS analysis similarly to the FT TIMS method. The clear advantage of SEM-EDX/TIMS over FT TIMS is that it is less time consuming and does not require a reactor facility [41].

Another option which is not commonly used yet in nuclear safeguards is to perform chemical separations on single

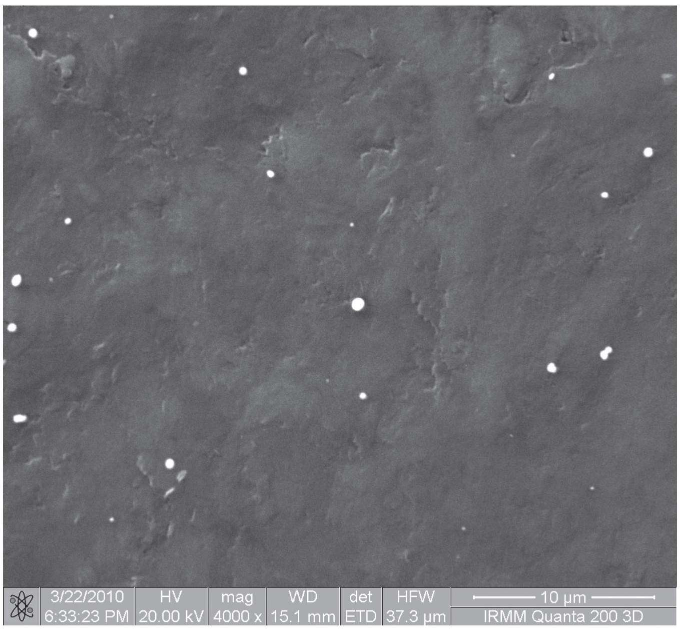

Figure 4: IRMM uranium reference particles (picture courtesy of IRMM) [47].

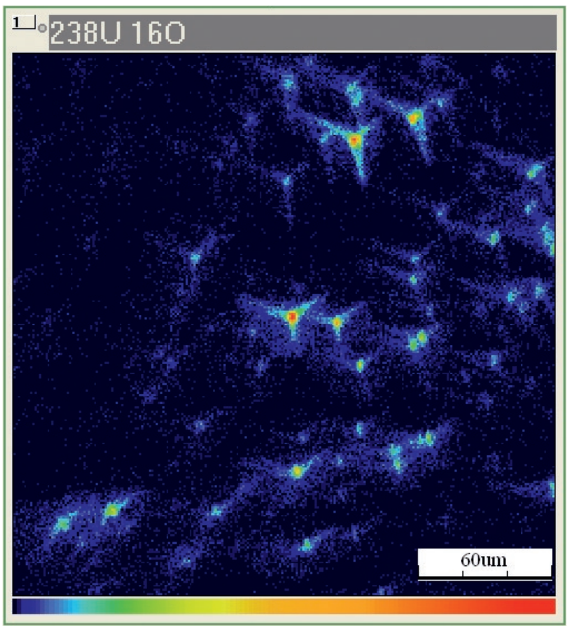

Figure 5: Ion image of uranium reference particles by SIMS (picture courtesy of ITU) [43].

particles in order to remove isobaric interferences for isotope dilution mass spectrometry or isotope ratio assay: single particles are identified and relocated by SEM-EDX and chemically separated/spiked prior to the TIMS measurement [41]. This technique has for instance been used by the authors of [46] for age determination of single plutonium particles.

3.1.4. Laser Ablation Inductively Coupled Mass Spectrometry

Laser ablation inductively coupled mass spectrometry (LA-ICP-MS) has not been implemented as a routine method for the analysis of single particles in nuclear safeguards yet. It seems, however, to be a promising technique offering rapid and accurate determination of the isotopic composition of individual uranium particles [47]. Similarly to techniques using TIMS, particles of interest have to be identified before the mass spectrometric measurement but moving single particles to filaments is not necessary: The surface holding the particles is placed in the laser ablation chamber of the laser ablation system and a laser beam is focused on the surface of a single particle. An aerosol is formed when a laser beam strikes the surface of the sample. These aerosol particles are transported into the inductively coupled argon plasma by an argon gas flow where they are atomized and ionized. The ions are separated according to their mass to charge ratio in the mass spectrometer either in a quadrupol or in a combination of electrostatic analyser and magnetic sector field. Instruments deploying the latter principle exist as single and multi detector instruments (simultaneously detecting several signals) while quadrupol instruments only have a single detector. Sector field instruments can be operated in higher mass resolution ($m/\Delta m$) than quadrupol instruments. The authors of [48] developed for instance a method for the measurement of ^{234}U, ^{235}U, ^{236}U and ^{238}U isotopes in single particles with diameters down to 10 µm. Especially multi-collector sector field instruments show potential for the analysis of safeguards related particle samples offering short analysis time and minimal sample preparation [49]. The accuracy of measurement of the uranium isotope ratios is limited due to the short transient signals from laser ablation with prompt signal variations and to potential fragmentation rather than vaporization of particles. LA-ICP-MS measurement performance for a single particle with a size of about 1 µm or smaller is not yet adequate for routine safeguards analysis. LA-MC-ICP-MS for particle analysis is a technique under development that should be further investigated and improved. Particularly the combination of multi-collector sector field ICP-MS with femto second lasers might be promising for particle analysis. Advantage of LA-MC-ICP-MS is that less complex sample preparation in combination with shorter time for analysis leads to a higher potential sample through-put compared to SIMS or TIMS analysis [47].

4. Benefits and drawbacks of Destructive Analysis

The major benefit of DA in nuclear safeguards clearly lies in the high quality of the obtained measurement results that are provided to safeguards authorities. DA is the basis for a system of accurate measurement results for uranium and plutonium isotopic compositions and element concentrations with small combined uncertainties conform to the latest standards in nuclear safeguards. State of the art analytical procedures and measurement techniques in combination with the correct use of reference materials and quality control tools establish traceability, reliability and comparability of measurement results in fissile material accountancy and environmental sample analysis. Therefore the availability and development of suitable nuclear reference materials for method validation and instrument calibration is a prerequisite [50]. DA methods are the methods of choice when accurate and reliable measurement results with uncertainties estimated according to international guidelines are required, increasing the confidence in the conclusions drawn by safeguards authorities [51].

DA is also the strategy of choice for special samples (in terms of isotope composition, sample matrix or concentration), environmental samples and non-routine samples such as sized material in nuclear forensic investigations: Whenever nuclear material is discovered in places out of the regulatory control of nuclear safeguards, nuclear forensic investigations are applied in addition to traditional forensics. Nuclear forensics focuses on reconstructing the origin and the history of the sample. Isotopic and elemental compositions as well as physical appearance are analysed. In this way information on the production process, intended use and age of the material can be obtained [52]. The questions to be answered are similar in case of "forensics" samples and single particles from swipe samples routinely taken in nuclear facilities. The origin and history (production process, intended use, age) are also of interest for these samples. Single particle analysis, however, has to deal with the added difficulty of very small sample sizes (pg-range). Highly sensitive and accurate measurement methods as offered by DA are beneficial to cope with such small amounts of analytes.

The major drawbacks of DA are that DA is time consuming and expensive compared to NDA: High investments need to be made in order to obtain and maintain high precision analytical instruments. DA techniques may also be more demanding in terms of operator skills. Both timely delays until the measurement data are available as well as higher costs compared to NDA originate partially in the need of transporting the samples to the safeguards laboratory where they are analysed: The transport of nuclear samples is logistically challenging because special licenses are required and transport regulations are stringent. The disadvantages of timely delay as well as costly and logistically challenging sample transports can partially be overcome by measurement campaigns in on-site laboratories. On-site laboratories are directly located at the inspected facilities. Euratom operates such on-site laboratories for instance in nuclear reprocessing plants in Cap de La Hague in France and in Sellafield in the UK [53]. Furthermore combined methods such as COMPUCEA also allow in field-measurements at nuclear installations.

Another drawback is that for DA analyses aliquots from a (large) bulk of nuclear material is taken. Conclusions on the whole bulk of nuclear material are drawn by safeguards authorities based on accurate measurement results of these sub-samples under the assumption that these samples taken by inspectors are representative for the whole badge. Thus DA also requires a well considered sampling strategy on the collected samples to be verified by independent measurements, which introduces an additional uncertainty component to the final result.

Furthermore nuclear waste is generated when DA is performed creating additional costs as well as logistic and environmental considerations concerning treatment, transport and storage. The waste needs to be transformed in a physical form that is suitable for storage in order to reduce volume and/or weight: compressing of un-burnable waste, combustion of burnable waste and evaporation of solvent in case of liquid waste. It is then eventually transported for final storage and/or recycling.

4.1. DA or NDA?

DA involves measurement techniques which are carried out in such a way that the sample being measured is not returned to the batch it was taken from, hence introducing a significant change. Contrary to DA, NDA can be performed without changing the physical and/or chemical form of the sample. Thus by means of NDA equipment installed in a nuclear facility the material flow can even be followed and monitored via remote data collection. Radiometric techniques do not even require the opening of sample containers since the radiation emitted by the nuclear material is measured. These radiometric techniques can be subdivided in either be passive and active measurement techniques. The first measures radiation produced by spontaneous decay while the latter measures radiation induced by activation of the sample material with an external source. The purpose of both DA and NDA is to measure the concentration (amount) and isotopic composition (enrichment) of nuclear material. The major points to be considered when choosing the appropriate measurement technique from all the possibilities offered by both NAD and DA are:

- the required accuracy and selectivity of the measurement method which influences the overall measurement uncertainty;
- the acceptable time delay from sampling until the data are available which is directly linked to the safeguard goal of “timeliness of detection”;
- the total cost from sampling till data generation and interpretation including transport issues and waste management.

Summarising it can be said that the method of choice has to be suitable for the analyte under investigation and “fit for purpose” taking into account the available resources., Availability of analytical instruments and authorised operators has to be taken in account when deciding not only between NDA and DA but also when choosing the appropriate method within NDA and DA methods, respectively [1]. Both DA and NDA methods have to meet the International Target Values for Measurement Uncertainties in Safeguarding Nuclear Materials. The International Target Values are uncertainties to be considered in judging the reliability of analytical techniques applied to industrial nuclear and fissile material, which are subject to safeguards verification [2]. DA and NDA techniques are complementary in providing answers on specific safeguards questions in fissile material accountancy and environmental analysis. In this light the ESARDA DA and NDA working groups are regularly holding joint meetings being a platform of exchange of information on DA and NDA methods among experts from safeguards authorities, industry and research organisations.

5. Conclusion

Destructive Analysis is one of many complementary measures applied in Nuclear Safeguards, which help to monitor and optimise the successful implementation of the safeguard goals as defined in the NPT and the Euratom treaty. A great variety of analytical methods ensures that the information needed to answer specific questions relevant to nuclear safeguards can obtained. Different analytical methods are needed to cope with samples of different sizes, concentrations and enrichment as well as chemical and physical form. DA and NDA supplement each other in this task. They play, therefore, along with other safeguards strategies a vital role in promoting the peaceful use of nuclear energy and in counteracting the abuse of nuclear material.

6. Acknowledgement

The author would like to thank the Working Group on Training & Knowledge Management of the European Safeguards Research and Development Association for organising the 6th ESARDA course on Nuclear Safeguards and Non Proliferation.

7. List of abbreviations

AP	Additional Protocol of the Non-Proliferation Treaty
COMPUCEA	Combined Procedure for Uranium Concentration and Enrichment Assay
DA	Destructive Analysis
EDX	Energy Dispersive X-ray spectrometry

EU	European Union
Fe	Iron
FT TIMS	Fission Track Thermal Ionization Mass Spectrometry
GD-MS	Glow Discharge Mass Spectrometry
HF	Hydrofluoric acid
HKED	Hybrid K-Edge/K-XRF Densitometry
IAEA	International Atomic Energy Agency
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IDMS	Isotope Dilution Mass Spectrometry
KED	K-Edge Densitometry
LA-ICP-MS	Laser Ablation Inductively Coupled Mass Spectrometry
LEU	Low-Enriched Uranium
LG SIMS	Large Geometry Secondary Ion Mass Spectrometry
MOX	Mixed plutonium and uranium Oxide
NDA	Non-Destructive Analysis
NPT	Non-Proliferation Treaty
Pu	Plutonium
SEM	Scanning Electron Microscope
SEM-EDX/TIMS	combination of Scanning Electron Microscopy, Energy Dispersive X-ray spectrometry and Thermal Ionization Mass Spectrometry
SG SIMS	Small Geometry Secondary Ion Mass Spectrometry
SIMS	Secondary Ion Mass Spectrometry
SIMS	Secondary Ion Mass Spectrometry
SS-MS	Spark Source Mass Spectrometry
TIMS	Thermal Ionization Mass Spectrometry
U	Uranium
UF_6	Uraniumhexafluoride
XRF	X-Ray Fluorescence (XRF)

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Technical sheets

3D Laser-Based Scene Change Detection for Basic Technical Characteristics / Design Information Verification

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1. Introduction

The EURATOM Treaty stipulates in its Article 78 that "anyone setting up or operating an installation for the production, separation or other use of source materials or special fissile material or for the processing of irradiated nuclear fuels shall declare to the Commission the Basic Technical Characteristics (BTC) of the installation" so that the Commission is able to "satisfy itself that, in the territories of the Member States, ores, source materials or special fissile material are not diverted from their intended use as declared by the users" (Article 77). BTC are to be provided at least 200 days before the first arrival of nuclear material. For new installations, other than Locations Outside Facilities (LOF), it is however required to provide relevant information on the installation 200 days before construction begins. The preparation of BTCs in such a case is normally a step-wise process.

From the IAEA side, in accordance with paragraph 48 of INFCIRC/153, the design information is verified periodically, throughout the lifetime of a facility, on a continuing basis at existing facilities under safeguards. This verification contributes to the cumulative knowledge of the facility design, its operation, the continued validity of the safeguards approach and evaluation of resource requirements.

The BTCs (or in IAEA terms: Design Information – DI) describe in detail:

- the intended use of the installation and the nuclear material (NM),
- how the accountancy and the yearly inventory taking will be performed,
- on which places the NM is located for different operating states (so called key measurement points – KMP),
- which are the possible routes for NM between the KMPs.

The BTC shall be verified visually at the latest at the beginning of the plant operation (BTC Examination) and then re-examined at least once per year during the Physical Inventory Verification (PIV) to confirm its continued validity or any declared changes. For a new installation the BTC verification may also be done in a step-wise mode in accordance with the construction process.

The increasing size of nuclear facilities and the complexity of their design and processes pose many technical challenges to the development of tools assisting inspectors in verifying the BTC and, more generally, in accurately detecting changes occurred.

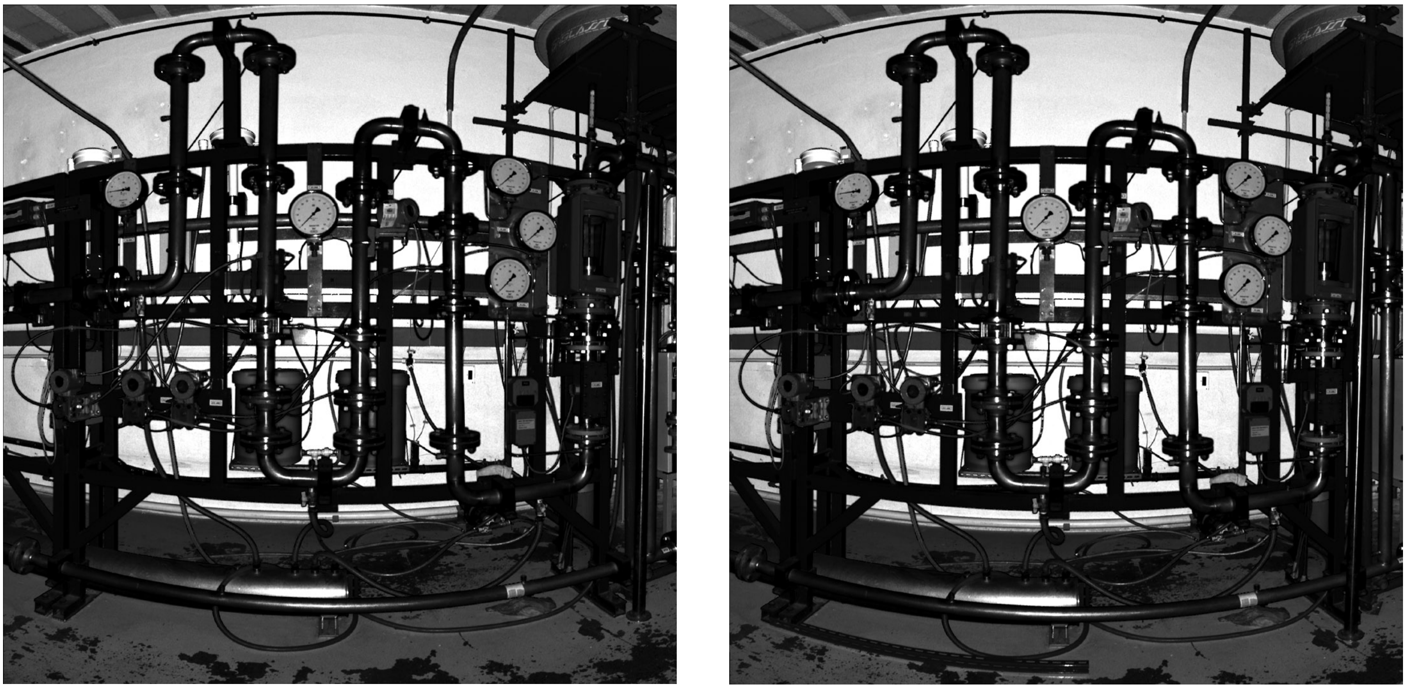
As an in-depth verification of all areas during the PIV is beyond Inspectorates' resources and often causes large irradiation doses, a structured, methodical approach is taken prioritising equipment, structures and activities and randomizing the lower priority items. Even with prioritised tasks and with the application of a random approach, the verification activities, especially in large drum stores, for cell and piping verification in reprocessing plants remains a tedious and time demanding activity. Therefore a device is useful which can check in acceptable time the change of complex structures like pipes in reprocessing plants or possible drum movements in large storages.

Also the fact that BTC activities must take place over several years (involving different staff) represents additional problems, the issue of maintaining continuity of knowledge of the previously verified equipment and structures being with no doubt the most important one, not only during the construction phase but also for the entire life of the plant.

This ESARDA technical sheet details the use of a 3D laser-based scene change detection system as a tool to assist inspectors in identifying minute changes in complex industrial scenes. The technical sheet focuses on the capabilities and principles of operation of this 3D verification system.

2. Application background

Visual observation for the verification of BTC can be extremely difficult in complex environments such as industrial plants. This is particular true for a next generation of new, complex installations. As an example, Figure 1 shows a reduced area of pipe work at an R&D laboratory, both before (a) and after (b) having introduced some changes.



(a) Reference (b) Verification

Figure 1: Example of a complex scene to be verified: pipework at an R&D laboratory (courtesy of ABACC).

From the figure it becomes obvious that it can be extremely difficult to spot whether differences have been introduced, considering:

- A simple comparison of two pictures before-and-after is not reliable due to *too sensitive picture* position taking and *illumination conditions*. Further, normal plant maintenance may require *re-painting* parts of the scene which, in terms of simple picture comparison, may lead to many false alarms. This creates difficulties in assessing what has *really* been changed in the plant.
- A plant is a complex three-dimensional entity, and it is difficult to be completely described "as-built" by a mere set of photographic images.
- The period between the verification exercises can be of the order of months.
- There may be rotation of inspectors making the verification, i.e., a new inspector assigned to a plant may not be fully acquainted with the plant operation and its evolution in time.

These considerations led to the development of a 3D laser-based modelling and scene change detection system to assist inspectors in identifying changes at a given environment.

This ESARDA technical sheet focuses on the capabilities and principles of operation of this 3D verification system. The system is divided into two main components:

(i) a commercial-off-the-shelf laser range scanner for data acquisition, i.e., capture the 3D coordinates, of a given environment and

(ii) a suite of software applications needed to (a) create an accurate 3D reference model, (b) automatically analyse a verification model, (c) detect changes, as well as (d) manage all acquired and processed datasets, including secure storage and data authentication.

3. Laser scanning and 3D models

Within the context of this technical sheet, the word '3D' or three-dimensional indicates the capability to measure distances accurately. Different distance measurement systems are characterised by their measurement accuracy, measurement resolution (also called depth resolution), spatial resolution (defined by the inter-sample distance at the surface of the object, or by the minimum inter-sample angle referenced to the sensor).

The use of 3D laser-based scene change detection is based on the following:

a) It is possible to create accurate 3D models of existing environments "as-built".

b) Changes in an environment are more robustly detected in 3D (i.e., using depth or distance measurements), than in 2D (e.g., by processing surveillance images).

Equipment

Laser Range Finders (LRF) are instrumental for contactless, accurate distance measurement. LRFs are electronic instruments emitting a narrow laser beam. When the laser beam hits an object, part of its energy is reflected and detected by the LRF instrument. There are different physical principles to measure distances using LRFs:

i) ***Time of Flight:*** The instrument uses a pulsed laser beam. The measurement technique is based on the measurement of the time-of-flight, i.e., the time elapsed between the emission of the laser pulse and the reception of the corresponding echo. The elapsed time is proportional to the distance to the object.

ii) ***Phase Shift:*** Instruments using this technique emit a continuous laser beam modulated by a sine wave. The instrument continuously measures the shift in phase between the emitted beam (reference) and the detected echo beam. The phase shift is proportional to the distance to the object. For better accuracies, multiple modulating signals are often used.

Laser Range Finders (LRF) only measure distances along a given direction, i.e. the direction of the laser beam. To cover a wider space (i.e., solid angle), instruments normally use mirrors and/or mechanical scanning systems to deflect the laser beam. These instruments are known as **Laser Range Scanners**. Typically, Laser Range Scanners are able to deflect the laser beam inside a solid angle of 360° by 180°, which, in practice, corresponds to the whole space around the instrument.

In recent years, many companies have introduced new 3D laser scanning products, providing a wide variety of distance measurement equipment, to be used in many application areas.

3D Models

Cloud of Points: A laser range scanner can make 3D measurements of a whole scene (i.e., solid angle of 360° by 180°) in a few minutes with millimetre accuracy. The set of all 3D measurement points constitutes a *cloud of points*. These points are the simpler expression of a *3D Model*, i.e., a description of the scene being studied.

3D models serve multiple uses:

(a) ***Scene documentation:*** A geometrically accurate, interactive, three-dimensional description of an environment "as-built". When combined with colour photographs, this description is a good tool for planning, training, etc.

(b) ***Verification of BTC:*** Basically the comparison of two or more models acquired at different time instants, and the corresponding detection and reporting of the changes occurred.

(c) ***User Interface:*** Integrating the 3D model of the scene with scene related measurements and information, e.g., temperature, gamma and neutron radiation, materials, annotations, etc.

4. 3D laser-based methodology for verification of BTC

The verification of the Basic Technical Characteristics using laser range scanners is based on the following steps:

(i) ***3D Reference Model:*** Creation of the model to be used as reference for the Safeguards relevant areas to be verified in the future. The reference model should be as accurate and complete as possible. It should be acquired with the best possible conditions, including

a) higher spatial resolution,

b) lower measurement noise, and

c) multiple scans to allow for possible occlusions (i.e., one object hiding another). The number of scans required to produce a complete model of the scene depends on the scene complexity.

(ii) ***BTC Examination:*** If required, there may be an initial comparison between the 3D Reference model "as-built" with the plant CAD model or engineering drawings.

(iii) ***BTC Verification:*** Following a specific Safeguards criterion, an area for verification is selected, and a 3D model is created with fresh data.

> ***N.B.*** *There is absolutely no need to physically locate the laser scanner at the same position from where the data used for the reference model was acquired. It is enough that the scanner 'sees' the scene to be verified from a similar view. The verification software compensates for the different data capture locations. Further, the laser scanning equipment can be different, i.e., with different measurement accuracy as well as different spatial and depth resolutions.*

The new model is then compared with the Reference model and changes automatically identified. The result of the change-detection is a displacement-map. The verification phase can occur at any time after the reference model is constructed.

(iv) ***Presentation of Results:*** The displacement map is graphically presented to the inspector who, depending on the location and intensity of the changes, may decide to investigate further. It is possible for the inspector to document the inspection making annotations on the *Verification* scan.

5. 3D lased-based system for BTC: equipment and guidelines

3D Data acquisition equipment

A laser range scanner is used to acquire the 3D data which, when processed and integrated, will constitute the model describing a given environment. Figure 2 shows a 3D laser scanner meeting BTC verification operational requirements. Table 1 describes some relevant features of this device.

Max (min) Distance	79 (1.5) m
Measurement Accuracy	3 mm
Horizontal Spatial Resolution (max measurements over 360°)	40,000
Vertical Spatial Resolution (max measurements over 360°)	40,000
Measurement Speed (max) (measurements per second)	500,000
Weight	14 kg

Table 1: Technical features of the 3D laser scanner.

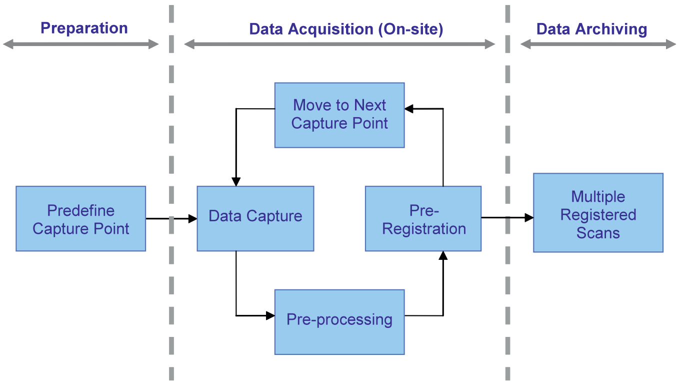


Figure 3: On-Site Data Acquisition and Pre-Processing for tripod based scanners.

The laser scanner can be placed "stand-alone" or on a tripod with a dolly. One should note that a single scan does not normally capture all the geometry of a scene. This is due to the presence of occlusions (i.e., one object behind another object not being captured by the laser scanning process). As such, multiple scans from different positions are needed to create a complete model.

Data Acquisition Guidelines

Figure 3 illustrates the workflow followed for the creation of a 3D model of a given environment based on data acquired from multiple scans. The following aspects need to be considered during data acquisition:

Occlusion and shadows: The scanning position should be planned carefully to avoid missing data. Holes and occlusions (reflecting the absence of data) become evident when data is later processed. The BTC verification software allows the *in situ* registration of the acquired scans so that holes and occlusions can be immediately detected and resolved.

Acquisition Angle: Very shallow (i.e., acute) angles between the laser beam and objects surfaces affect the quality of the final model both in terms of distance accuracy and spatial resolution (i.e., spatial detail).

Scan overlap: The registration of data from different capture positions requires sufficient overlap between scans.

Uniform scan resolution: Scanner viewpoints and resolution should be selected to yield a fairly uniform spatial resolution. This leads to a 3D model with not too varying geometrical properties.

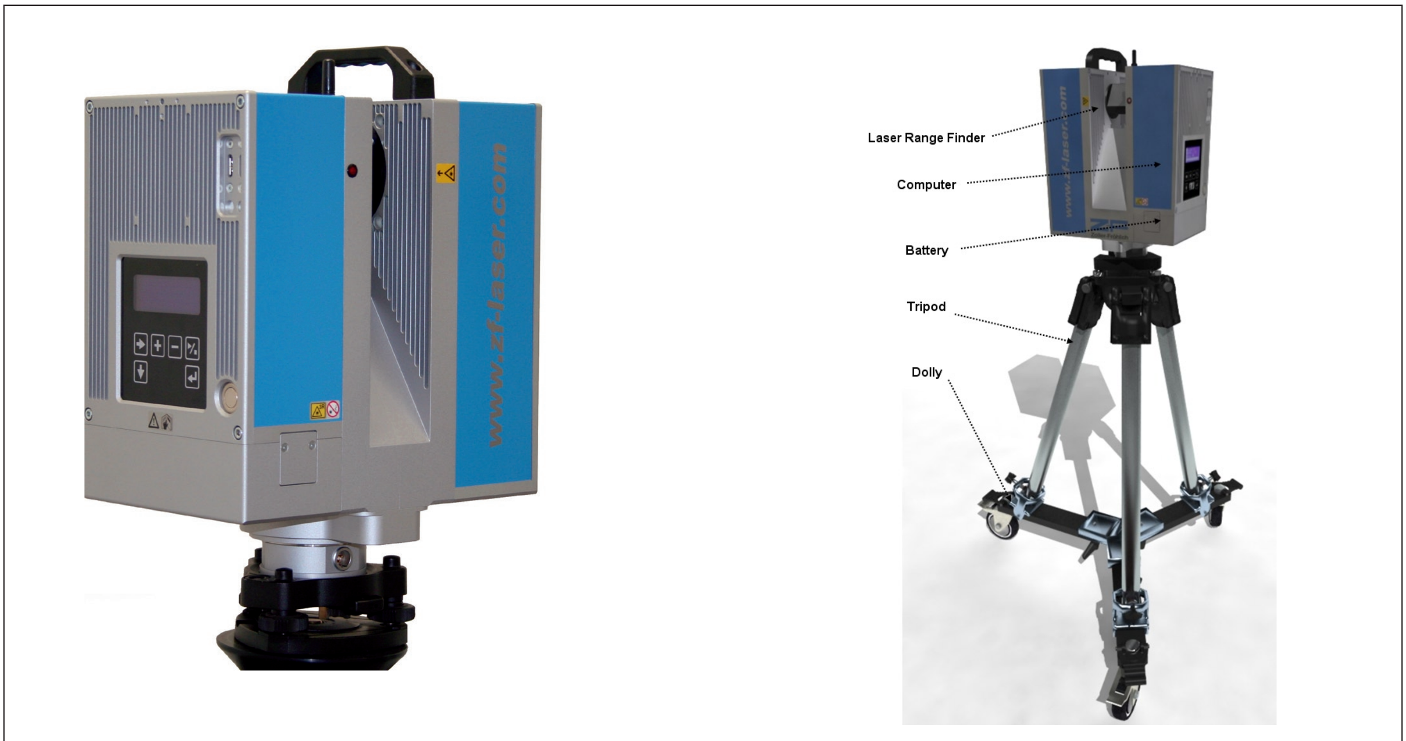


Figure 2: 3D data acquisition equipment.

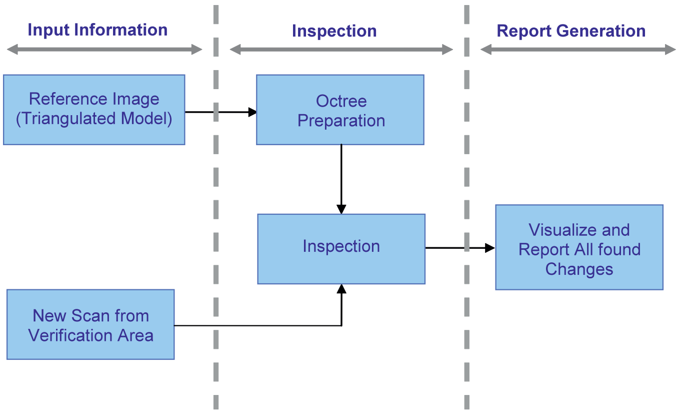


Figure 4: Inspection and Verification process.

6. BTC verification software

The BTC verification software is constituted by a suite of applications. A full description is beyond the scope of this Technical Sheet. Some of its main modules are:

Registration: Finds the geometric transformation between the 3D datasets acquired at different locations. The registration uses data from overlapping areas between the different views to compute the exact location of one view in respect to another.

Data Fusion: Combines data from different datasets. The fusion process keeps the most suited data aiming at the best quality possible 3D model, and discards redundant data.

Data Triangulation: Creates a 3D model described by triangular surfaces. It uses as input a cloud of 3D points (the laser scanner measurements) and produces as output a surface, represented by a myriad of individual triangles. The size of each triangle is adapted to match the scene spatial details, i.e., larger triangles for smooth areas, such as walls, and smaller triangles to preserving the spatial detail of smaller features, such as pipes.

Model Comparison: This module is used to detect changes as in the case of BTC Verification. It uses as input the triangulated 3D Reference Model and the Cloud of Points for the area to be verified[1]. It outputs a map of 3D displacements for the scene area to be verified.

Presentation Software: This module provides the verification results to the inspector. It takes as input a 3D displacement map and presents it to the inspector, who can interactively set some visualisation parameters, such as to scale the displacement map to discriminate smaller objects better. Two pseudo-colour schemes are frequently used: (a) *Distance-based Pseudo colouring* – a continuous representation of the distances measured, associating a neutral colour to very low distances and an alarm colour (normally red) to larger distances; (b) *Colour-coding with alarm level* – shows only the objects which have moved more than a given distance (interactively set by the inspector). The result can be treated in such a way that areas or volumes which have distance changes above a threshold are saved to an inspection log file containing a global unique location reference (xyz location and extension).

Figure 5 shows an inspection result with this colour coding technique.

7. Training effort

Since 2006, regular hands-on courses on the use of 3D Design Information Verification system have taken place in collaboration with the IAEA. The 5-day course is organised to provide inspectors with a conceptual perspective of how the 3D verification system works, followed by practical sessions where groups of two inspectors create the reference model and make the verification of a given industrial environment. Other training actions have taken place and are envisaged at EC DG ENERGY, Luxembourg, and at ABACC, Brazil.

[1] Given that the cloud of points representing the area to be verified was very likely acquired at a location different from the acquisition of the reference data, there is no guarantee that the 3D points in the two data sets (i.e., reference and verification) coincide. Thus, the verification is not based on a direct point-to-point comparison, but rather on a point to model surface comparison (technical details are beyond the scope of this text).

Figure 5: Reference model (left), verification scan (middle), automatically detected differences in red (right).

8. Discussion

Different methodologies have been made available for BTC verification, most of them based on visual observation or image comparison. When applied to large, complex industrial environments, detection of spatial changes is challenging and difficult.

There are two main advantages for the 3D laser-based BTC verification system:

a) It is possible to create a highly accurate representation – millimetre accuracy – of the scene under verification in a few minutes. This representation can be as complete as desired and the inspector has full control on data quality.

b) Given the system's accuracy and completeness, it is possible to detect any structural change, even minor, introduced in the plant. This provides further confidence in the capabilities of the 3D BTC verification system.

The following operational notes should be taken into account:

- One should be aware that not all changes correspond to Safeguards relevant events. Indeed, it is up to the inspector to interpret changes and record the corresponding annotations. The 3D BTC verification system does not replace the inspector; it simply assists him/her in detecting regions where spatial changes occurred.
- The fact that the whole process is computerised eases the provision of the necessary continuity of knowledge for the lifetime of the facility.
- From a practical point of view, an inspectorate needs to have a laser scanning system that can be resident at a given facility, or shared among facilities. The system packs easily into a relatively small hard case (42 x 55 x 26 cm, 21.5 kg) that can be checked-in for international flights.
- Being a new technology, it is expected that improvements may come from future commercial 3D laser scanning devices – faster, with better spatial resolution and more accurate. Further, practical input and feedback received from end-users (i.e., inspectors) are to be taken into account for future versions of the software.

As a last point, Figure 6 shows the automatically detected 3D scene change detection for the scenario described in Figure 1. Two visualisation schemes are presented.

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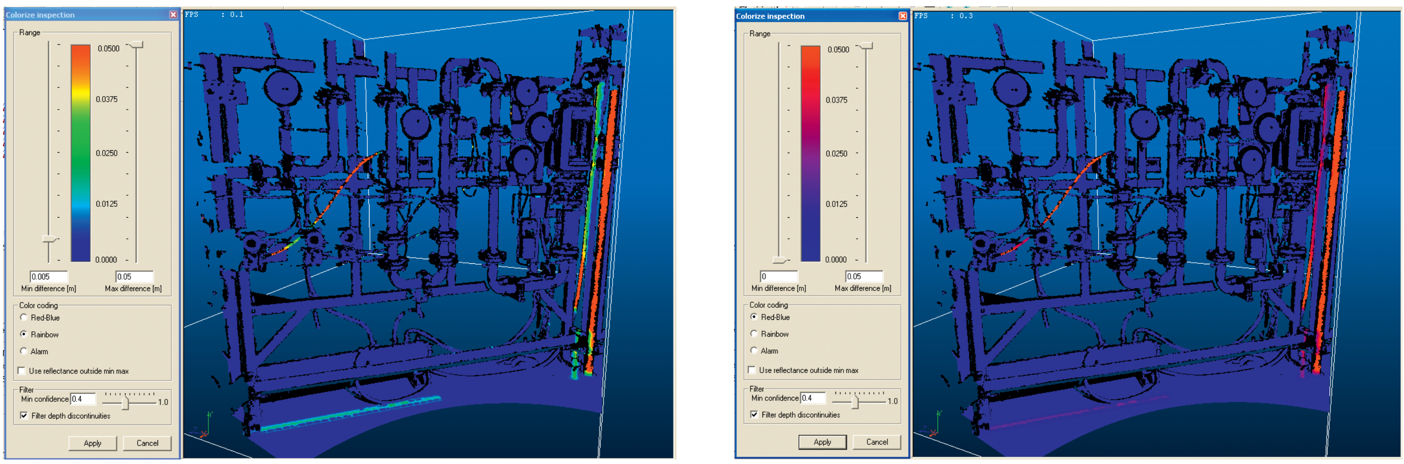

Figure 6: Identified 3D Changes (see Figure 1) visualised with two different colour code schemes (Dark blue 0.005 m – Red 0.05 m).

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LB-AB-10-045-EN-C

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