INTERNATIONAL TARGET VALUES – LOOKING FORWARD AND LESSONS LEARNED

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ABSTRACT

Under the State-level concept, nuclear material accountancy (NMA), which supports the detection of diversion of nuclear material from declared nuclear fuel cycle (NFC) facilities is reaffirmed as a measure of fundamental importance. The effectiveness of safeguards verifications in support of NMA depends, on the one hand of the quality of the NFC facility operators' accounting and measurement system and, on the other hand, of the performance of the inspectors' non-destructive assay (NDA) in-field measurement and of destructive analysis (DA) of nuclear material samples. In order to assess and compare the quality of safeguards measurements, a set of uncertainty values for destructive analysis (DA) was proposed by the European Safeguards Research & Development Association (ESARDA) Working Group for Destructive Analyses (WGDA), and the first values were published in 1979. The WGDA released three subsequent updates, and in 1993, the International Atomic Energy Agency (IAEA) published the ITV derived primarily from safeguards measurement data collected in NFC facilities all over the world. Two subsequent updates, progressively extending the ITV scope, were released by the IAEA in 2000 and 2010 following the same approach. The ITV-2020 project, whose objective is to issue the next set of updated and expanded ITV had to face a number of challenges related to the Covid-19 pandemic and the subsequent lockdown conditions at the IAEA and in partner Member State institutions. Fortunately, the proactive and early engagement of international stakeholders and the lessons learned from virtual meetings led the authors to consider a more continuous approach to ITV that would be more dynamic and collaborative, more resilient to resource disruptions, and more adaptive to changes in international communication culture and platforms.

INTRODUCTION

The first generic safeguards objective of safeguards implementation at the State Level [1], [2] is *the detection of diversion of declared nuclear material at declared facilities or locations outside facilities (LOFs).* It is also the core technical objective of safeguards implementation under a CSA. as described in Article 28 of INFCIRC/153 (Corrected), Part II [3]: *The agreement should provide that the objective of safeguards is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection.*

As is further described in Articles 29 and 30 of INFCIRC/153 (Corrected) [3], the objective of diversion detection is pursued by applying nuclear material accountancy (NMA) to all declared *nuclear material*, i.e., any fissionable or source material as defined in Article XX of the IAEA Statute [4]. The principle of NMA and its keystone, material balance evaluation (MBE), is to detect and deter diversion by evaluating the nuclear material balances established through the State's system of accounting for and control of nuclear material (SSAC) against the corresponding uncertainties. Nuclear material inventories in nuclear fuel cycle (NFC) facilities and movements between NFC facilities are declared to the IAEA by the State through formalized State reports for all material balance areas (MBA) within facilities and for periods called material balance periods (MBP). The credibility of the IAEA's conclusions regarding non-diversion can only be warranted if the State's accounting declarations are verified by the IAEA's inspectors through independent observations and quantitative measurements.

A large portion of IAEA inspectors' time is used for carrying out in-field measurements by various non-destructive assay (NDA) techniques, and/or for taking destructive analysis (DA) samples for analysis by the safeguards analytical laboratory (SAL) in Seibersdorf, Austria or other IAEA certified laboratories of the IAEA network of analytical laboratories (NWAL). The effectiveness of the IAEA's verification strongly depends upon the quality of both the facility operator's declarations and the inspector's measurements. A commonly agreed reference system is needed to assess and compare measurement qualities. Paragraph 55 of INFCIRC/153 (Corrected), Part II [3] stipulates: *The Agreement should provide that the system of measurements on which the records used for the preparation of reports are based shall either conform to the latest international standards or be equivalent in quality to such standards.*

In the 1970s, the IAEA established a set of international standards of nuclear material accountancy defined as values of the measurement uncertainty δ_E (relative standard deviation) expected for closing a material balance, for different types of facilities [5]. Presently, the δ_E values can still be used as global limiting criteria in the field of material balance at the MBA level. However, they are values reflecting measurement performance achievable by NFC operators several decades ago. They have not been revised and, importantly, they do not provide the reference framework needed for assessing the measurement uncertainties associated to specific measurands, specific DA or NDA methods, and specific material types encountered in NFC facilities. For these reasons, a different approach was initiated in the late 1970s, leading to the introduction of International Target Values (ITV). Section 1 of the present paper summarises the history of ITV. The definition of ITV is presented in Section 2. The long-term actions taken to address questions raised at the occasion of the ITV-2010 review, the lessons learned during the preparation of the ITV-2020 edition and a proposal to evolve the ITV process are described in Section 3.

1. A BRIEF HISTORY OF ITV

In 1979, the Working Group on Techniques and Standards for Destructive Analysis (WGDA) of ESARDA presented a list of "Target Values" for uncertainty components in destructive analysis (DA) methods" to the IAEA and EURATOM [7]. After extensive consultations with NFC facility operators' laboratories and safeguards organizations, these first target values were revised in 1983 [8]. The ESARDA WGDA, in collaboration with the Institute of Nuclear Materials Management (INMM), published random and systematic uncertainties to be aimed for in elemental and isotopic analysis of the most significant material types encountered in the NFC using common DA methods in 1987 [9]. The same groups took a new step in the 1988 edition [10] when they agreed to define the values of the random error uncertainty to be met in the elemental assays as a result of sampling.

Following a recommendation made in 1988 by the IAEA Standing Advisory Group on Safeguards Implementation (SAGSI), the IAEA convened a Consultants Group Meeting (CGM) in June 1991 to provide expert advice on international standards of measurements applicable to safeguards data. A concept of International Target Values (ITV) was proposed on the model of the 1988 ESARDA Target Values and included estimates of the *random and systematic error uncertainties originating from the measurements of volumes or masses of nuclear materials*. The scope of ITV was also extended beyond destructive analysis (DA) methods to include non-destructive assay (NDA) methods, which had won acceptance as accountancy verification tools. Specialists from four continents took part in the discussion of the proposed concept. The result was the publication of an IAEA Safeguards Technical Report (STR) in March 1993, entitled *1993 International Target Values for Uncertainty Components in Fissile Isotope and Element Accountancy for the Effective Safeguarding of Nuclear Materials* [11]. Articles in the ESARDA Bulletin [12] and in the Journal of the INMM [13] widely publicized the IAEA technical report. The report itself was translated into Japanese [14]. In 2000, international experts reviewed the experience gained with the use of the 1993 ITV and the progress made in accountancy and safeguards verification measurements. Subsequently, an IAEA STR entitled *International Target Values 2000 for Measurement Uncertainties in Safeguarding Nuclear Materials* [15] was published in April 2001 in the ESARDA Bulletin [16] and in the Journal of the INMM [17].

Each issue of ITV is related to a given year, reflecting a recognition that the quality of measurements may change, that new methods and instruments may be developed and implemented and that others may become obsolete. The ITV also reflect the current understanding of the structure of the uncertainty components in nuclear material accountancy measurements.

The last (current) version titled *International Target Values 2010 for Measurement Uncertainties in Safeguarding Nuclear Materials* was published in 2010 as STR-368 [6].

2. WHAT ARE ITV?

ITV are values of uncertainties, expressed as relative random and systematic error standard deviations associated with a single determination result, which should be achievable under nominal conditions by a typical NFC facility laboratory on one sample or the result of an NDA measurement performed on a single item. ITV intend to take into account all sources of measurement errors, including sources which may not be known, in uncertainty estimates resulting from analysis of variance applied to operator-inspector paired data and reviewed by subject matter experts (SME). They are applicable to the accountancy data collected by the inspectorates and reflect measurement uncertainties that should be achievable under regular conditions by typical NFC facility laboratories or during safeguards inspections (Fig. 1 State of Practice). It is important to note that they should not be interpreted as uncertainties that can only be achieved under ideal laboratory conditions (Fig. 1 State of the Art). Likewise, they do not represent regulatory requirements but rather a motivating goal – as their name “target values” suggests - and a reference for experienced laboratories and safeguards inspectors and evaluators.

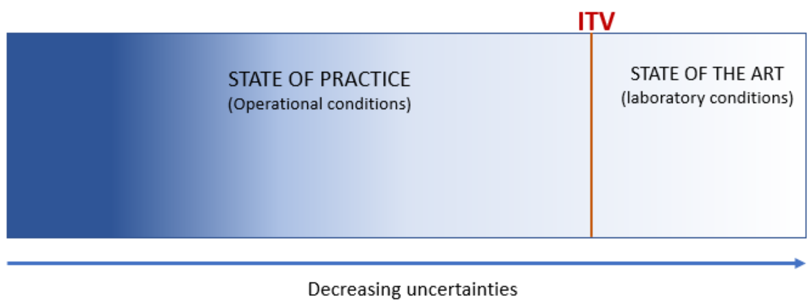

Figure 1: International Target Values are measurement uncertainties that should be achievable under nominal conditions by typical NFC facility laboratories or during safeguards inspections but should not be interpreted as uncertainties that can only be achieved under ideal laboratory conditions

3. ITV-2020: ACHIEVEMENTS, LESSONS LEARNED AND LOOKING FORWARD

3.1 Extension and organisation of the ITV SME network

Extensive efforts were initiated at an early stage of the ITV-2020 update preparation in order to ensure a broad international outreach and identify representatives from the different safeguards communities who could provide the sources of expertise represented in Fig. 2, i.e., analytical laboratories, NDA laboratories, safeguards data evaluators from national and international inspectorates, NFC facility operators, and State or regional authorities responsible for safeguards implementation (SRA). It was considered that the participation of all parties involved in the use of ITV would warrant their quality, representativeness and achievability, ensuring that they can be used as a credible reference by the broadest possible range of safeguards practitioners. Information about the ITV-2020 project was presented in the framework of a large number of international nuclear safeguards meetings such as:

- The 41st ESARDA Symposium, Stresa, Italy (14-16 May 2019);
- The 60th INMM Annual Meeting, Palm Desert, CA, USA (14-18 July 2019);
- The Joint Meeting of INMM ASC N15 and N15-5.1 (12 July 2020 - virtual);
- The International Technical Meeting on Statistical Methodologies for Safeguards (2-6 November 2020 - virtual);
- The ESARDA DA and NDA Working Group Meeting (18 November 2020 – virtual);
- The International Workshop on Uranium and Plutonium Isotopic Analysis by Non-Destructive Assay Techniques for Nuclear Safeguards (16-18 February 2021 – virtual).

In addition, the topic of ITV-2020 was discussed in meetings with experts from State authorities and national organisations involved in nuclear measurement, for example:

- The Nuclear Material Control Center (NMCC) (19 June 2019, Tokyo, Japan);
- The GT35 CETAMA (4 February 2020, Paris).

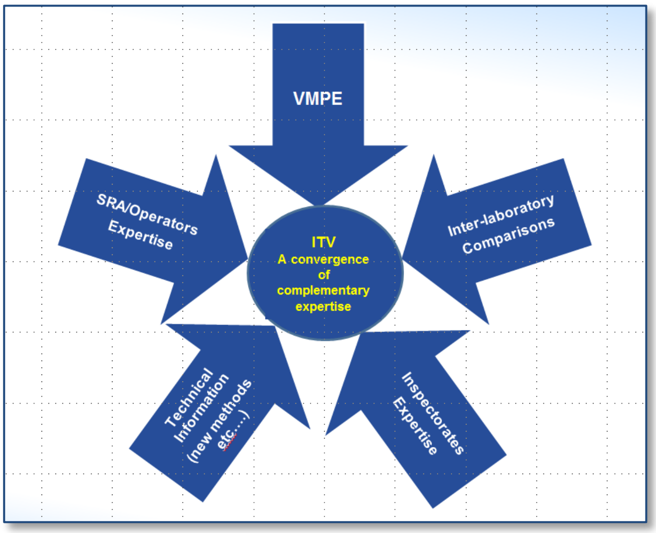

Figure 2: Bringing together different sources of expertise and recognizing their synergy and complementarity is essential to ensure the quality and usability of ITV-2020.

An official request for support was issued through the IAEA Member State Support Program (MSSP) under the International Target Value (ITV-2020) task proposal, in order to secure funding and ensure coordination of the participating SME effort. At the time of the CGM (May 31st – June 17th 2021), 12 MSSP Member States had accepted the task or shown interest in contributing to the project.

In parallel, the IAEA established the project's organisational structure in terms of Areas of Expertise (AoE), each coordinated by an IAEA expert. IAEA coordinators are in charge of:

- Organising outreach in their area of expertise and liaising with international experts;
- Reviewing the ITV-2010 tables to identify obsolete entries and identify the need for new entries and/or tables;
- Organising the review of the initial values established by IAEA evaluators based on historical data;
- Collecting and reviewing components of the ITV-2020 report narratives in their area of expertise;
- Preparing the 2021 Consultant Group Meeting (CGM).

Each AoE was further divided into more specialised sub-groups. Eight NDA sub-groups were identified: 1-COMPUCEA; 2-U/Th Content; 3-^{235}U enrichment; 4-Pu isotopics; 5-U/Pu mass by gamma measurements; 6-U/Pu mass by neutron measurements; 7-Weighing; 8-Volume and Density. The four DA sub-groups created were DA-I: Titration and Mass Spectrometry, DA-II- Spectro(photo)metry, XRF/K-edge, Polarography, Calori-/Coulo-/Gravimetry, DA-III: Cristallini & Sampling and DA IV-Eastern Time Zone. A sub-group leader was appointed in each sub-group to organize the sub-group work, report its progress and draft meeting minutes. Kick-off meetings were held for the NDA and DA communities in order to identify sub-group leaders and participants. A guidance presentation was given by the IAEA to summarize the main objectives of the ITV-2020 exercise and the tasks of the AoE sub-groups. The sub-groups were asked, *inter alia*, to review the ITV table structure and, in the absence of estimates based on the IAEA database, e.g. for new methods or in case of insufficient statistics, to provide prospective uncertainty estimates based on technical expertise or experience, with a view to compare them with ITV when enough implementation data would become available. About 140 initial implementation data-based ITV were estimated by the IAEA evaluation team in the 2nd semester of 2020 and the 1st semester of 2021. All sub-groups held regular virtual meetings to review these estimates in preparation of the virtual CGM which was successfully held in June 2021. In order to foster and facilitate communication within sub-groups and with the IAEA while leveraging the remote communication culture which emerged from the Covid-19 pandemic conditions, a virtual platform (Fig.3) was developed, featuring a discussion board, information about the sub-group members, access to the CGM sessions, ITV-relevant resources, e.g, the ITV-2010 STR and other references, a library to store documentation generated by the sub-groups and a link to support workflow and document action items.

3.2 Methodological reconciliation efforts

During the ITV-2010 CGM, a debate took place between members of the CGM about the consistency between ITV and the recommendations of the *Guide to the Expression of Uncertainty in Measurement* (GUM) re-issued in 2008 as JCGM 100:2008 [18].

In summary, the objective of the GUM is to provide measurement laboratories with a standardized, methodical approach to determining a quantitative measurement uncertainty associated with a measurement result. Its application also ensures that laboratory results are transparent and traceable and can be compared. The GUM uses a modelling approach based on establishing a functional relationship between the measurand and a set of input quantities and on determining the combined uncertainty for a measurement result using error propagation algorithms. One of the main advantages of this procedure is to ensure that laboratories identify all significant contributors to their uncertainties, i.e. establish a reliable *uncertainty budget*. In 2010 the GUM had been widely adopted by safeguards laboratories. Since the GUM is essentially concerned with associating a single measurement result with a reliable uncertainty (expressed as a total standard deviation multiplied by a coverage factor), some CGM members questioned the fact that ITV are expressed in terms of two components: the relative random error standard deviation and the relative systematic error standard deviation.

Safeguards evaluators explained that this distinction is essential when propagating uncertainties to the sums of measurement results that form the components of material balances and that the methodologies used for MBE rest on a statistical model of measurement error which is fit for purpose and is not in contradiction with the GUM. The IAEA model was developed to support the detection of nuclear material diversion in the context of the implementation of safeguards agreements. It is used for the estimation of measurement uncertainties from operator-inspector differences - also referred to as paired data - by statistical analysis of variance methodologies. The estimated measurement uncertainties are expressed as relative standard deviations (RSD), often denoted by the Greek letter δ, and are used by safeguards inspectors for establishing sampling plans and determining significance limits for operator-inspector differences observed during inspections. They are also the uncertainties applied by safeguards data evaluators in performing material balance evaluation when a statistical analysis is needed, e.g. to detect diversion in bulk handling facilities.

A consensus was reached on adding an additional column representing the total uncertainty, combined from its random and systematic components. However, the ITV-2010 CGM debate revealed the need for a constructive methodological and terminological communication between different safeguards communities involved with measurements and measurement uncertainties and drew the participants' attention on the common benefits of opening communication channels and intensifying exchanges between these communities before the next ITV issue: ITV-2020.

In the wake of the ITV-2010 CGM, representatives from all stakeholder groups were identified and communication channels were opened, inter alia, in the context of ESARDA working groups and the biennial IAEA International Technical Meetings on Statistical Methodologies for Safeguards: several interactive seminars took place to review and compare measurement uncertainty quantification concepts, methodologies as well as the expression of uncertainties. Their main purposes were:

- to identify commonalities and differences and the associated rationales in order to promote a mutual understanding of other communities' objectives in applying uncertainty concepts;
- to distinguish between terminological differences and conceptual or methodological differences; and
- to recognise complementarities and opportunities for mutual learning and methodological synergies.

In order to provide momentum and encourage progress towards these objectives, it was decided to describe the reconciliation efforts in a common paper. The representatives of different communities contributed different sections of the paper now referred to as the "Reconciliation Paper" [23].

The main outcome of the reconciliation efforts is an agreement by all parties that the GUM and the statistical model used by safeguards data evaluators are not contradictory, but complementary and fit for different purposes. Importantly, their mathematical equivalence was demonstrated and a glossary of terms used in the field of measurement uncertainties was established with a view to clearly distinguishing terminological and conceptual differences. Moreover, opportunities for mutual learning and methodological synergies were identified and the IAEA is now exploring hybrid uncertainty quantification methods that combine elements from complementary approaches. It was further recognised that a comparison between GUM-based bottom-up uncertainties and the top-down estimates obtained by applying the IAEA statistical approach can help identifying sources of measurement errors unaccounted for and building more complete measurement models, especially in the field of NDA. Last but not least, closing the communication gap between ITV stakeholders and fostering mutual understanding was expected to facilitate collaboration during the preparation of the ITV-2020 review.

3.3 Lessons learned and proposals for the future of ITV

Like many other activities around the world, the ITV-2020 project was impacted and delayed by the COVID-19 pandemic and the resulting lockdown of the IAEA headquarters. During the setback period, core activities had to be adapted to remote collaboration and communication practices and took priority, initially encroaching upon the ITV-2020 project. However, the IAEA evaluators took this opportunity to revisit the ITV process, integrate improved uncertainty quantification methodologies and software into the ITV estimation process and develop automated algorithms to increase the efficiency of the evaluations and harmonize procedures. Lessons learned during this period and the extended use of virtual meetings led the IAEA to consider a new approach based on a collaborative web-based platform to update ITV in a continuous way, based on real-time triggers as opposed to the 10-year cycle review. The proposed approach would:

- be more resistant to disruptive events and resource impacts;
- be more dynamic and collaborative;
- be a more modern approach (web-based rather than paper-based);
- enable the IAEA to share interactive electronic tools;
- avoid facing the same open questions every ten years due to loss of focus; and
- maintain an active – although less resource-intensive - network of SME and have regular exchanges on topics related to ITV, e.g., methodologies, standards.

The proposal for a continuous ITV review process was presented to the CGM participants for consideration. Its implementation needs to be examined in terms of resources required by the network of SME and vetted by the participating MSSP Member States which authorise, organise and fund their participation.

CONCLUSION

An international reference system is needed to assess the quality of both the nuclear fuel cycle facility operators' declarations and the safeguards inspectors' verification measurements and to ensure the effectiveness of the independent verification by the IAEA of nuclear material quantities reported by States under their safeguards agreements. Extensive outreach efforts have been made since 2019 to take into account the expertise of all international safeguards stakeholders, and ensure that they work in synergy to optimize the quality, credibility and usability of the ITV-2020 revision. In the course of the decade following the current ITV-2010 publication, exchanges were intensified with the different safeguards communities involved with measurements and measurement uncertainties in order to reconcile methodologies and terminology and to identify opportunities for mutual learning and synergies. Improved uncertainty quantification methodologies and software have also been integrated into the ITV estimation process, while procedures were automated and harmonized. Lessons learned from virtual exchanges during the COVID-19 pandemic led to the creation of a collaboration platform to prepare the ITV-2020 Consultant Group Meeting (CGM) and a proposal was made to the CGM participants to leverage the new distance collaboration culture to evolve the ITV review from a 10-year cycle to a continuous but less resource-intensive process.

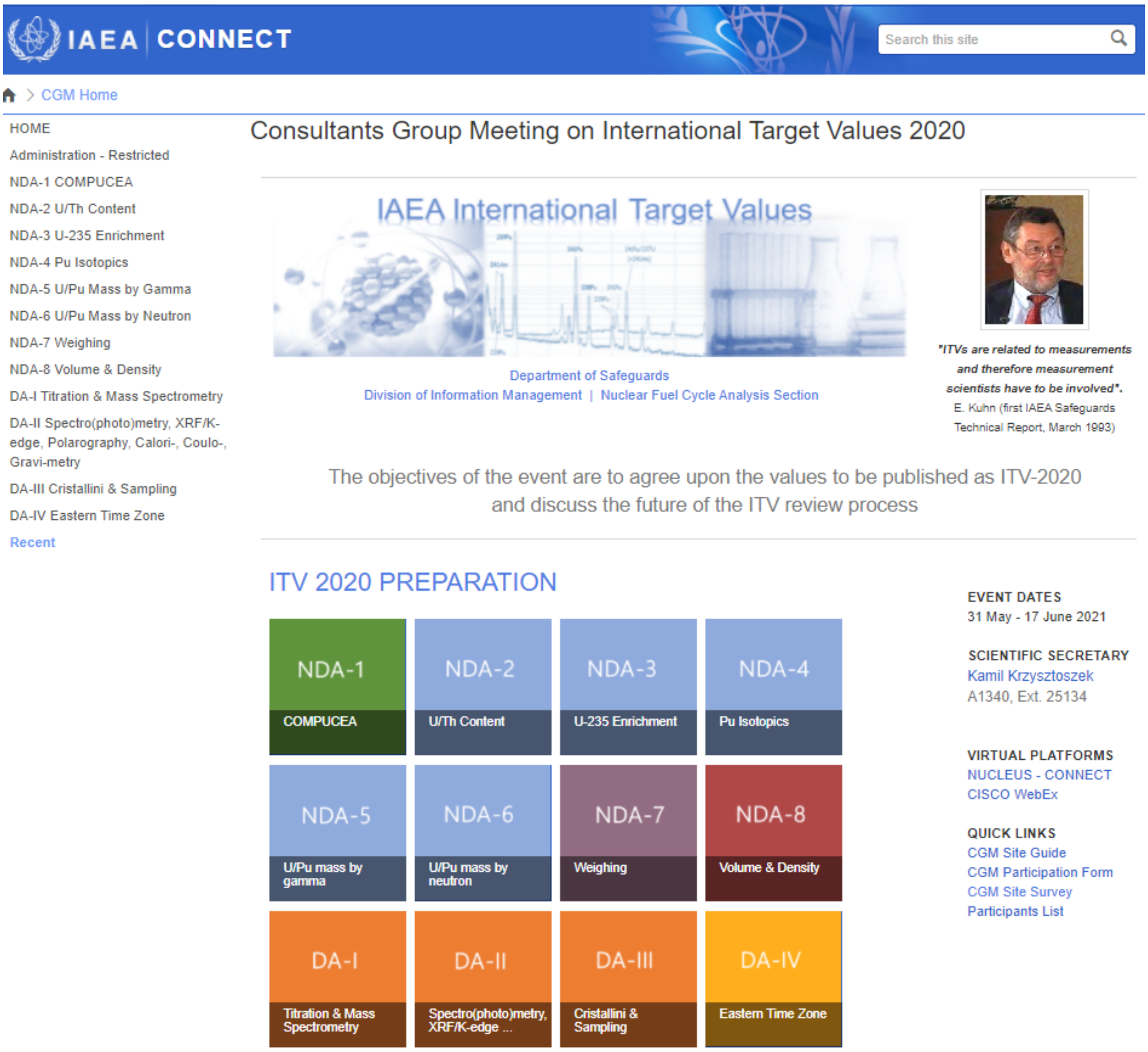

Figure 3: a virtual platform was developed to support the June 2021 CGM by leveraging the remote communication culture which emerged from the COVID-19 pandemic conditions.

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REFERENCES

[1] The Conceptualization and Development of Safeguards Implementation at the State Level, GOV/2013/38, IAEA, Vienna (2013).

[2] Supplementary Document to the Report on The Conceptualization and Development of Safeguards Implementation at the State Level (GOV/2013/38), GOV/2014/41, IAEA, Vienna (2014).

[3] The Structure and Contents of Agreements between the Agency and States in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, INFCIRC/153 (Corrected), IAEA, Vienna (1972).

[4] IAEA Statute, IAEA, Vienna (amended in 1989).

[5] IAEA Safeguards Glossary, IAEA, Vienna (2001).

[6] IAEA, International Target Values 2010 for Measurement Uncertainties in Safeguarding Nuclear Materials, STR-368, IAEA, Vienna (2010).

[7] DE BIEVRE, P., DE REGGE,P., Target Values for uncertainty components of destructive analysis methods, Minutes of the Meeting of the ESARDA/WGDA in Brussels, April 23-24, 1979, SCK, Mol, Belgium (1979).

[8] DE BIEVRE, P., et al., 1983 Target Values for uncertainty components in fissile element and isotope assay, ESARDA Bulletin 6 (1983).

[9] DE BIEVRE, P., et al., 1987 Target Values for uncertainty components in fissile isotope and element assay, IAEA proceedings of the 1986 Symposium on Nuclear Safeguards Technology 649-662, IAEA, Vienna (1987)

[10] DE BIEVRE, P., et al., Random uncertainties in sampling and element assay of nuclear materials; target values 1988, ESARDA Bulletin 13 (1987).

[11] KUHN, E., et al.,1993 International target Values for Uncertainty Components in Fissile Isotope and Element Accountancy for the Effective Safeguarding of Nuclear Materials, IAEA STR-294, IAEA, Vienna (1994).

[12] DERON, S., et.al, 1993 International target Values for Uncertainty Components in Measurements of Nuclear Material for Safeguards Purposes, ESARDA Bulletin 23, JRC Ispra (1994).

[13] DERON, S., et.al. 1993 International Target Values for Uncertainty Components in Fissile Isotope and Element Accountancy for the Effective Safeguarding of Nuclear Materials, Journal of Nuclear Materials Management, Volume XXII, Number II, January 1997.

[14] 1993 International Target Values for Uncertainty Components in Fissile Isotope and Element Accountancy for the Effective Safeguarding of Nuclear Materials, Japanese Translation, Science and Technology Agency, Japan, (1993).

[15] AIGNER, H., et. al., International Target Values 2000 for Measurement Uncertainties in Safeguarding Nuclear Material, IAEA, STR-327, IAEA, Vienna (2001).

[16] AIGNER, H., et. al., International Target Values 2000 for Measurement Uncertainties in Safeguarding Nuclear Material, ESARDA Bulletin 31, JRC Ispra (2002).

[17] AIGNER, H., et. al., International Target Values 2000 for Measurement Uncertainties in Safeguarding Nuclear Material, IAEA, Journal of Nuclear Materials Management, Vol. XXX, No. 2 (www.inmm.org/itvs/1698.htm).

[18] Evaluation of measurement data – Guide to the expression of uncertainty in measurement. JCGM 100:2008.

[19] NORMAN, C., BAUTE, J., BINNER, R.,NIKKINEN, M., WALCZAK-TYPKE,A., Evolution of Verification Data Evaluation under the State-level Concept, 39th ESARDA Annual Meeting, Düsseldorf, Germany (2017).

[20] NORMAN,C.,KRIEGER,T.,BINNER,R.,BONNER,E.,PETER,N.,PORTAIX,C.,RICHET,S., WALCZAK - TYPKE,A., WÜSTER,,J., ZHAO,K.; Outcome and Perspectives from the first IAEA International Technical Meeting on Statistical Methodologies for Safeguards; Proceedings of the IAEA International Safeguards Symposium, Vienna, Austria (2014).

[21] K.MARTIN, Estimation of Variances of Random and Short-Term Systematic Measurement Errors based on Data from Two and Three Independent Measurement Methods – An introduction to the evaluation of measurement uncertainties; software package OPTANOVA- (2018).

[22] NORMAN,C., BINNER R., BALSLEY S., International Target Values (ITV) 2020: The Role of Stakeholders, Institute of Nuclear Materials Management (INMM) 60th International Meeting, Palm Desert, USA, 14-18 July 2019.

[23] ALIQUE,O.,AREGBE,Y., BENCARDINO,R., BINNER,R., BURR,T., CHAPMAN,J. A., CROFT,S.,FELLERMAN,A., KRIEGER,T.,MARTIN,K., MASON,P.,NORMAN,C.,PROHASKA,T.,TRIVEDI,D.,WALSH,S.,WEGRZYNEK,D., WRIGHT,B., WÜSTER,J., Statistical error model-based and GUM-based analysis of measurement uncertainties in nuclear safeguards – a reconciliation, *draft submitted to Metrologia, 2021.*