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INTERNATIONAL TARGET VALUES 2010 FOR ACHIEVABLE MEASUREMENT UNCERTAINTIES IN NUCLEAR MATERIAL ACCOUNTANCY

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ABSTRACT

The International Target Values (ITVs) are reasonable uncertainty estimates that can be used in judging the reliability of measurement techniques applied to industrial nuclear and fissile materials subject to accountancy and/or safeguards verification. In the absence of relevant experimental estimates, ITVs can also be used to select measurement techniques and calculate sample population during the planning phase of verification activities. It is important to note that ITVs represent estimates of the “state-of-the-practice”, which should be achievable under routine measurement conditions affecting both facility operators and safeguards inspectors, not only in the field, but also in laboratory. Tabulated values cover measurement methods used for the determination of volume or mass of the nuclear material, for its elemental and isotopic assays, and for its sampling.

The 2010 edition represents the sixth revision of the International Target Values (ITVs), issued by the International Atomic Energy Agency (IAEA) as a Safeguards Technical Report (STR-368) [1]. The first version [2] was released as “Target Values” in 1979 by the Working Group on Techniques and Standards for Destructive Analysis (WGDA) of the European Safeguards Research and Development Association (ESARDA) and focused on destructive analytical methods. In the latest 2010 revision, international standards in estimating and expressing uncertainties have been considered while maintaining a format that allows comparison with the previous editions of the ITVs. Those standards have been usually applied in QC/QA programmes, as well as qualification of methods, techniques and instruments.

Representatives of the Brazilian Nuclear Energy Commission (CNEN) and the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC) participated in previous Consultants Group Meetings since the one convened to establish the first list of ITVs released in 1993 [3] and in subsequent revisions, including the latest one in 2010. This paper summarizes the history of the ITVs, presents the main changes introduced to the latest revision in comparison to the previous 2000 revision [4] and discusses possible impacts of these changes on plant operators, safeguards inspectors and laboratories.

1. INTRODUCTION

Among others safeguards activities carried out at a nuclear facility, independent quantitative verifications of the declared amounts of fissile materials are performed by safeguards inspectors. The effectiveness of these activities depends to a great extent upon the quality of the measurements achieved by both the facility operator in declaring the amounts of nuclear materials present in his facility and the safeguards inspectorate. For this reason, Safeguards Agreements [5] in connection with the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) stipulate that the system of measurements on which the facility records used for the preparation of reports to the international and regional inspectorates are based, shall either conform to the latest standards or be equivalent in quality to such standards.

With the objective to establish standards on expected uncertainty components for the operator's declarations and the independent inspectors' verification measurements, in 1979 the Working Group on Techniques and Standards for Destructive Analysis (WGDA) of the European Safeguards Research and Development Association (ESARDA) has pioneered by presenting a list of so-called "Target Values" [2] to the safeguards authorities of the European Atomic Energy Community (EURATOM) and the IAEA.

Subsequently, in recognition of the high importance of the evaluation of the quality of safeguards analytical measurements, the IAEA started convening every two years an Advisory Group Meeting to discuss progress in the area. In the meeting of October 1981 in Vienna, with the participation of 19 representatives from 10 member States and EURATOM and staff from the IAEA Secretariat, among others, the Advisory Group recommended to the IAEA to collaborate with ESARDA in order to establish a single list of "Target Values".

Following several years of extensive discussions within the ESARDA-WGDA and consultation with and within analytical laboratories and safeguards organizations, revised uncertainty estimates were prepared and published as the "1983 Target Values for uncertainty components in fissile element and isotope assay" [6]. This document was intended to provide estimates of the measurement performance which could reasonably and realistically be attributed to analytical laboratories (state-of-the-practice performance). Performances were expressed as the experimental standard deviation of a single determination under reproducibility conditions (random character) and the estimated standard deviation of the correction factors (systematic character).

Despite all efforts made by the "1983 Target Values" to consider the total analytical uncertainty from both measurement and sample treatment errors, it did not include estimates due to sampling errors because, at that stage, it had not yet been possible to evaluate them properly. The objective was to give a global estimate of all uncertainties occurring after the sampling, taking into consideration the safeguards requirements for each type and category of nuclear material.

A revised document, entitled "The 1987 Target Values for Uncertainty Components in fissile Isotope and Element Assay" [7] was published and reflected the experience gained in the use of the concept of target values and the progress observed in analytical performance since 1983.

Following the publication of the "1987 Target Values", it was recognized that uncertainties associated with the sampling operation could also contribute significantly to the overall uncertainty of a measurement process. It led to the preparation of a combined list of "Target Values for Random Uncertainties in Sampling and Element Assay", valid from 1988 onwards, under routine conditions and updated as warranted by changes in the state-of-practice. The document was published as the "1988 Target Values for Random Uncertainties in Sampling and Element Assay" [8].

Seeking advice on the definition of “International Standards of Measurement” for Safeguards purposes as above-referred in this paper and recommended by the IAEA´s Standing Advisory Group on Safeguards Implementation (SAGSI), in June 1991 the IAEA decided to convene a consultants´ group meeting from which it was decided to prepare the “International Target Values (ITVs) for the uncertainty components in fissile isotopes and element accountancy”. A concept of International Target Values (ITVs) was proposed on the model of the 1988 ESARDA Target Values and included estimates for the “random” and “systematic” uncertainties associated with measurements of volume and total mass of nuclear material. The scope of ITVs was also extended to include estimates for non-destructive assay methods (NDA), which had won wide acceptance as useful accountancy verification tools.

The Draft ITV´s for both Destructive Analysis (DA) and Non-Destructive Analysis (NDA) were derived from a critical examination of reported measurement performances and safeguards requirements, and were submitted to various technical meetings and groups for review, such as ESARDA/WGDA/NDA, the subcommittees of INMM, ISO/TC85/SC5/WG3 and the Japan Atom Forum. Through representative of the Brazilian National Energy Commission (CNEN) present at the consultant´s meeting, a number of Brazilian and Argentine laboratory representatives had the opportunity to contribute to this review process.

Taking into consideration the Consultants´ recommendations, in March 1993 the IAEA endorsed and published the “1993 ITV´s” [3] “Safeguards Technical Report”. This reference of the International Standards of Measurements was included by the IAEA in its working procedures, as well as referred to in the NPT Agreements. Since that time, the IAEA has continued to monitor the uncertainty components observed in its verification measurements and examined this information periodically with the interested panels in order to keep the ITVs in line with technological advances and safeguards analytical requirements.

Since the publication of “1993 ITV´s”, two other revisions have been made, resulting in the “ITV´s-2000” [4] (with ABACC participation) and the “ITVs-2010” [1] (with ABACC and CNEN participation). The ITV´s-2000 were prepared on the basis of a critical discussion of the inspectorates´ performance evaluations of actual historical data and their comparison with the “1993 ITV´s”. Information provided by laboratories, arising from interlaboratorial measurement evaluation programmes and experimental validation of methods and instrumentation were used in the review process. A similar procedure was conducted for the preparation of the ITV´s-2010 (in comparison with ITV´s-2000).

2. THE ITV´s-2010

2.1. The Establishment of the Consultants' Group Meeting (CGM) for Discussing the Draft ITV´s-2010

In March 2010, the IAEA convened a three-day Consultants' Group Meeting (CGM) aiming at the revision and conclusion of the ITV-2010. The meeting was held at the IAEA Headquarters in Vienna, Austria, and had the following main objectives: to review the draft ITV updated tables as prepared by the IAEA and to provide recommendations for the values to be published as ITVs-2010; provide recommendations on the format and content of the ITV-2010. The meeting was considered an important step to ensure wide acceptance of the

ITVs-2010. It followed "outside" reviews previously conducted by working groups and organizations that are involved in the improvement, standardization and evaluation of quality of measurement techniques used in the accountancy and verification of nuclear materials. The IAEA counted on the expertise available in organizations and working groups as listed below:

- Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials – ABACC
- European Safeguards Research and Development Association – ESARDA
- *European Atomic Energy Community* - EURATOM
- Institute of Nuclear Materials Management - INMM
- International Organization for Standardization - ISO
- Japanese ITV Expert Group
- Nuclear Energy Commission of Brazil – CNEN

About ten staff members and one independent consultant represented the IAEA in the CGM.

In preparation for the meeting, the IAEA conducted "Verification Measurement Performance Evaluations" using historical Operator-Inspector differences from more than 20 years of international safeguards application in several member States. The data represented the main source of information for the preparation of the draft ITV-2010 tables. As result, new uncertainty estimates were calculated and proposed, as well as the deletion and addition of analytical techniques and some changes in the format of the tables.

About six months prior to the meeting, the IAEA sent to the experts the draft ITV-2010 tables for review and comments. The consultants were asked to consider performance values and measurement quality experience related to nuclear materials, as available in their respective working groups and organizations. In addition, the IAEA requested information on improvements in existing measurement techniques, or developments of new measurement methods that might be of relevance for the accountancy and safeguarding of nuclear materials, although not yet in routine use. Similarly to the IAEA, operator-inspector paired data collected by ABACC during actual safeguards inspections in Brazil and Argentina was considered as important source of information for the measurement techniques used for safeguards purposes in these countries (Brazil and Argentina have a specific Safeguards Agreement [9] with ABACC and IAEA). Measurement quality experience, as derived from QC/QA and inter-laboratory programs, are available to the above mentioned groups and organizations and represented another valuable source of information for defining measurement performance that should be achievable under the conditions normally encountered in typical industrial laboratories.

The following topics were covered during the CGM:

- Brief historical description of the ITV´s: from the first initiatives of ESARDA aiming at the establishment of target values for uncertainty components of destructive analysis methods to the current ITV concept.
- Results of IAEA´s verification measurement performance evaluations: presentation of summaries of actually observed measurement data for DA and NDA, based on the statistical evaluation of operator-inspector differences.
- Reports by the consultants on measurement quality experience related to nuclear

materials, as available in the respective working groups and organizations: actual data available to domestic and regional safeguards organizations, performance values from inter-laboratory programs, quality control data of measurement systems and validation of new methods and instrumentation.

- Improvements in measurement techniques and methodologies; new methods: the consultants reported on improvements in existing measurement techniques, including measurement procedures, calibration standards, modern instrumentation, and new codes for data analysis.
- Review of the draft ITVs-2010: the working groups and organizations presented a summary of the comments and recommendations originating from the previous outside review process of each of the draft ITV-2010 tables.
- Final discussions and establishment of recommendations aiming at the conclusion of the ITV´s-2010.

2.2. The Main Changes Included in the ITV´s-2010

This session presents the main changes included in ITV´s-2010 in comparison to the previous version (ITV´s-2000).

2.2.1. Nomenclature and format of the tables

The most recent internationally-adopted convention in expressing and estimating measurement uncertainties is the "Guide to the Expression of Uncertainty in Measurement" (GUM) [10]. The standardization approach proposed by GUM intends to provide enough transparency to the process of uncertainty estimation and adequate tools to conduct an inter-comparison of measurement results. In expressing a measurement result, the GUM suggests a single value for the uncertainty along with a "budget" that describes the relative contributions of all known sources that make up the total reported uncertainty. In other words, the GUM method includes uncertainties from the "traditional" random and systematic components, and in addition uncertainties from other "estimable" sources, assumed by the analyst as relevant to the measurement (e.g., those associated with temperature, day-to-day and analyst-to-analyst variations). This detailed uncertainty expression makes it possible to conduct a consistent analysis of the reported result and appropriate pair comparison.

In the ITV´s-2000, uncertainty estimates were expressed as a two component system designated as random and systematic. Although the 1995 version of GUM [11] has been considered in ITV´s-2000, the use of the term "uncertainty" was associated with both the random and systematic components. As result of intense discussions at the CGM, the ITV´s are now single expanded uncertainty values that are computed from the combination of the random and systematic components. This change reflects the GUM approach and stimulates laboratories to evaluate and report uncertainties in compliance with the guide. The values for random and systematic components are however still presented in the ITV´s-2010 tables to allow users to identify and use these separate components as necessary. In addition, chapter 4 of ITV-2010 was included to summarize the objectives of GUM and establish a link between these two documents.

Regarding the tables that present the ITV´s, a few changes were introduced in the 2010 version. The changes were suggested by the IAEA based on its experience in using the ITV´s-2000 document and with the main purpose of separating uranium and plutonium materials, as well as associated DA and NDA measurement methods. As result, the total number of tables changed from 7 to 10, as in the following table:

Table 1. List of Tables of ITV´s-2010.

Table 1	Measurement Method/Instrument Codes
Table 2	Bulk and Density Measurements
Table 3	Sampling Uncertainties for Element Concentration and ^{235}U Abundance
Table 4a	Uranium Element Concentration Measurements (DA)
Table 4b	Plutonium Element Concentration Measurements (DA)
Table 5a	^{235}U Abundance Measurements (DA)
Table 5b	^{235}U Abundance Measurements (NDA)
Table 6	Plutonium Isotope Assay of Pu and U/Pu materials
Table 7a	Total Mass of ^{235}U (direct NDA)
Table 7b	Total Mass of Pu (direct NDA)

2.2.2. New methods and materials

As result of the technological advances and research developments during the last ten years, new methods became available to accountancy and safeguards applications. Some of them have already been used in routine basis, while others have a potential for the future. It should be noted that a few methods and instruments that are not in use anymore have been deleted from the previous 2000 ITV´s.

In table 2, electromanometer for volume and density measurements was included. The importance of volume and density measurements for safeguards verification has increased during the last years mainly due to the strengthened safeguards measures applied to complex bulk facilities, especially conversion and reprocessing plants.

In table 4a, uranium with gadolinium (burnable poison) was included. Since this material is used in some types of power reactors (e.g. Light and Pressurized Water Reactors), it may be subject to uranium concentration measurements in fuel fabrication plants that handle it in bulk form. Polarography was also included as a good performance method to measure this material. Spectrophotometry was included for concentration determinations in uranium solutions. X-ray fluorescence was included as a new method, applicable to process analysis.

In table 4b, new options for plutonium concentration measurements were introduced mainly due to advances in nuclear instrumentation for alpha spectrometry and neutron multiplicity counting. Calorimetry and coulometry were also included in the list. Pu-VI spectrophotometry and X-ray fluorescence were included for process analysis applications.

In tables 5a and 6, Multi-Collector Inductively Coupled Plasma Mass Spectrometry was included as a comparable option to the Thermal Ionization Mass Spectrometry.

In table 5b, one specific method for ^{235}U abundance measurement in reprocessed UO3 was included.

In tables 7a and 7b, new options for total mass determination by NDA were introduced mainly due to advances in neutron detection instrumentation and data analysis. One facility-specific measurement system for Pu inventory in glove boxes was included.

2.2.3. Uncertainty estimates

The ITV´s are intended to reflect the state-of-the-practice in regards to the performance of the methods commonly used for accountancy and safeguards purposes. Therefore, it becomes important to update the tabulated values at regular intervals in order to reflect the current level of quality of measurements. This quality may be affected by the development of newer methods and instrumentation and also by the enlarged experience that analysts and measurement collectors have obtained from the routine work.

In table 2, uncertainties for volume and density measurements are now better detailed. Careful calibration procedures for accountability tanks in large-throughput facilities have been developed and tested. As result, improved performance has been observed.

In table 3, a significant systematic component for ^{235}U abundance in sampling non-homogenized UF6 is now included.

In table 4a and 4b, separate uncertainty estimates are provided for U and Pu concentration analysis by Isotope Dilution Mass Spectrometry using large and small size spikes.

In table 5b, significant improvements in ^{235}U abundance were considered. This is mainly due to the notable advances in gamma spectrometry analysis codes, resulting in better background correction and peak area calculation. In table 6, the same reason resulted in improvements in Pu isotope assay by gamma spectrometry.

In table 7a, separate uncertainty estimates are provided for ^{235}U total mass determination in low (<20% $^{235}U/^{238}U$) and high (>=20% $^{235}U/^{238}U$) enriched uranium assemblies. The degradation of performance in the case of assemblies with high gadolinium (burnable poison) content was estimated.

In table 7b, the experience of the IAEA and facility operators in measuring MOX scraps and Pu wastes in reprocessing plants were considered in the corresponding revised values.

2.3. Possible Impact on Routine Accountancy and Safeguards Activities

The planning of activities of physical verification of nuclear materials for safeguards purposes is usually made based on the information on the methods available, the possibility of field use and expected performance. Therefore, it is clear that ITV's constitute an important source of information for planning purposes. Therefore, any changes to ITV's may incur changes in the planning process, the selection of a measurement method to be employed and the statistical calculation of the number of samples to be measured.

While ITV's are not intended to replace the actual performance data (historical) for a particular method, material and installation, they can simplify and expedite the process of planning physical verification activities. Statistic parameters associated with actual data may vary over time and are normally used to define acceptance criteria for the evaluation of individual results. Actual data inconsistent with the corresponding ITV's may indicate problems in the measurement process.

The inclusion of new methods in ITV's-2010 is a formal recognition of laboratories and safeguards organizations that they have adequate performance for use in nuclear material accountancy. Hopefully that from now on, plant operators and regulatory bodies make more use of these methods for generation and verification of accountancy data. This is the case of the Multi-Collector Inductively Coupled Plasma Mass Spectrometry method, which appeared as a comparable option to the Thermo Ionization Mass Spectrometry method. In addition, the inclusion of specific ITV's for uranium containing gadolinium shows the need for enlarged uncertainties for this type of material, which may impact sampling plan calculation.

In general, ITV´s-2010 reflect the progress made in the last decade in regards to techniques, analysis codes and measurement procedures. In particular, the improved performance of non-destructive methods for determination of uranium and plutonium isotopic composition by gamma-ray spectrometry was acknowledged. This technique is an important tool for process control and verification of declared data, since it normally has reduced cost and analysis time in comparison to destructive techniques. The ITV's-2010 shows this tendency and indicates that non-destructive techniques can be used increasingly in the future. On the other hand, additional research may be needed to improve the measurement performance in applications such as measurement of uranium with high gadolinium content used in specific types of power reactor fuels.

3. CONCLUSIONS

ITV´s continue to be a recognized reference in nuclear measurement uncertainties for accountancy laboratories and safeguards organizations in the process of evaluating and monitoring actual measurement performance values. In addition, safeguards inter-laboratory program organizers continue to rely on the ITV´s as a reference for evaluating measurements results.

Since some changes incorporated into ITV´s-2010 intend to reflect more closely the internationally adopted GUM approach, it is expected that, from now on, nuclear accountancy laboratories and safeguards organizations work towards evaluating and reporting uncertainties in compliance with the guide. This will bring additional transparency and confidence to the system. In addition, inter-laboratory programs are now expected to be prepared to provide evaluation outputs in compliance with ITV´s-2010 and GUM.

The increased amount of information suggested by the GUM approach in the process of estimating and expressing uncertainties has brought additional challenges not only to analysts, but also to the ITV´s. It is expected that future revisions present separate uncertainty estimates associated with contributors that are not yet clearly shown in ITV´s-2010. For example, high quality destructive measurements may depend significantly on the quality of the reference material used to determine corrections factors. Since a few reference materials for nuclear measurements are available, their influence in the final result for a particular method and material may be easily estimated. This information can be very useful to the ITV users.

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