Report on the Workshop on Reference Material needs and Evaluation of Measurement Uncertainties in Destructive (DA) and Non-Destructive Analysis (NDA)

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Abstract

The ESARDA Working Groups on Techniques and Standards for Destructive Analysis (WG DA); on Techniques and Standards for Non-Destructive Analysis (WG NDA); and on Novel Approaches/Novel Technologies (WG NA/NT) organised a dedicated workshop on *'Reference material needs and evaluation of measurement uncertainties in Destructive (DA) and Non-Destructive Analysis (NDA)'*. This workshop was hosted by the European Commission Directorate General Energy (DGENER) Nuclear Safeguards in Luxembourg from 5-7 March 2013. The workshop addressed the needs for standards/reference materials supporting DA and NDA instrument metrology and conformity assessment, and their application in estimation of measurement uncertainty including also uncertainty in nuclear data in view of new approaches in safeguards and needs for improvement of accuracy of existing DA and NDA techniques. The focus was to establish a regular exchange on these topics relevant to all three working groups with a special emphasis on supporting the needs of safeguards inspectors and evaluators. Participation was open to members and observers of the three ESARDA WGs, to DGENER and to a limited number of invited participants from expert and research institutes. Forty-nine representatives from the main European and international nuclear safeguards organisations, reference measurement institutes, metrology institutes, nuclear measurement laboratories, nuclear industry and from environmental sciences institutes participated in this workshop. The plenary lecture on '*Euratom safeguards – inspections – evaluations'* given by DGENER was followed by four sessions, the first on '*Safeguards - Inspections and Evaluations'*, the second on '*Destructive Analysis'*, the third on '*Non-Destructive Analysis'*, and the fourth session on '*Novel Technologies'*. The findings and points of discussion from these sessions were further discussed in a working group using the 'World-Café' approach around five selected topics, ensuring that all participants could benefit from the 'collective intelligence'. This report is a summary of the points of discussion raised during the sessions and in the working group. The WS participants proposed recommendations for setting priorities on needs of reference materials in DA and NDA, for strengthening the understanding based on metrological principles and the Guide to the expression of uncertainty in measurement (GUM) between different approaches in uncertainty estimation for DA/NDA, and in the evaluation of reported results. Furthermore recommendations were given in view of compliance with international standards and the implementation of quality systems. Research and development towards new methods, new instruments, novel technologies, and modelling should be carried out having in mind right

from the outset the requirements of feasibility, transparency, traceability and accuracy of measurement results. A particular outcome of this workshop was that all participants recognised the need and the benefit of intensifying cooperation and exchange between the safeguards; operators; research; and metrology communities, and follow-up activities were suggested.

Keywords: measurement uncertainty, nuclear safeguards, reference materials, International Target Values (ITV2010), nuclear material analysis, material accountancy, nuclear data, quality system

1. Introduction

Part of the scope of ESARDA is to provide a forum for the exchange of information and ideas between nuclear facility operators, safeguards authorities and institutions engaged in research and development. The permanent technical and scientific working groups are the key bodies of ESARDA, aiming to extend this interaction beyond the safeguards community to, amongst others, instrument developers, universities and metrology institutes by organising workshops on dedicated technical topics [1,2, 3, 4, 5, 6].

Destructive analysis and non-destructive measurement results for nuclear material accountancy and safeguards verification purposes have to be reliable and truly comparable, thus with demonstrated uncertainty and traceability, fit for intended purpose and within the required measurement uncertainties of the International Target Values for Measurement Uncertainties in Safeguarding Nuclear Materials (ITV2010) [7]. In May 2012, the three ESARDA Working Groups on *Techniques and Standards for Destructive Analysis* (WG DA), *Techniques and Standards for Non-Destructive Analysis* (WG NDA), and *Novel Approaches/Novel Technologies* (WG NA/NT), agreed to regular exchange on topics relevant to all three working groups. Following a recommendation of the previously held WGDA Workshop on *Uncertainties in Nuclear Measurements* [8], the three ESARDA WGs decided to address jointly the needs for standards/reference materials supporting DA and NDA instrument metrology and their application in estimation of measurement uncertainty, with an additional focus on uncertainty in nuclear data in view of new approaches in safeguards. The European Commission Directorate General Energy (DGENER) Nuclear Safeguards is currently implementing an integrated management system to conform to the latest international standard. The three ESARDA WGs particularly wanted to support these efforts by emphasizing in this workshop the exchange between the inspectors in the field, carrying out quantitative and qualitative measurements using a variety of instruments, and the institutes/laboratories that ensure accurate calibration of those instrumental systems. The announcement was distributed to members of all the three WGs and posted on the ESARDA web-site, with approximately about 50 participants ultimately contributing their expertise and knowledge to the success of the workshop. There was overall agreement on the usefulness of joint activities of the three WGs, In particular the participation from experts in the field of metrology was seen as extremely beneficial.

The institutions that participated in the workshop are listed in Table 1.

Table 1: List of participating institutions

Institution	**Country/organisation**
Commissariat à l'Énergie Atomique - CEA / DAM Ile de France	France
Commissariat à l'Énergie Atomique – CEA / DEN Marcoule	France
Commissariat à l'Énergie Atomique – CEA / DEN Saclay	France
Comprehensive Nuclear-Test-Ban Treaty Organization - CTBTO	United Nations
European Commission - Directorate-General for Energy - DGENER	European Commission
European Commission - Joint Research Centre-Institute for Transuranium Elements - EC-JRC-ITU	European Commission
European Commission - Joint Research Centre-Institute for Reference Materials and Measurements - EC-JRC-IRMM	European Commission
Forschungszentrum Jülich GmbH	Germany
International Atomic Energy Agency - Office of Analytical Services, Dept. of Safeguards - SGAS	United Nations
International Atomic Energy Agency - Division of Information Management, Dept. of Safeguards- SGIM	United Nations
International Atomic Energy Agency - Division of Physical and Chemical Sciences - Dept. of Nuclear Sciences and Applications - Nuclear Data Section	United Nations
Institut de Radioprotection et de Sûreté Nucléaire	France
Korea Atomic Energy Research Institute	Republic of Korea
SCK - CEN	Belgium
Sellafield Ltd	United Kingdom
Swedish Defence Research Agency, FOI	Sweden
STUK - Radiation and Nuclear Safety Authority	Finland
US - Department of Energy – New Brunswick Laboratory	United States of America
University of Natural Resources and Applied Life Sciences BOKU	Austria

2. Objectives of the workshop

The objectives of this workshop were quite ambitious and focused on the following:

- To facilitate a technical exchange on approaches to the quantification of measurement uncertainty among reference material institutes, safeguards laboratories, operators, safeguards inspectors and evaluators in DA and NDA
- To exchange on needs for accurate measurements in compliance with the Guide to the expression of uncertainty in measurement (GUM) [9] and the latest international standards for safeguards inspections in the field and safeguards nuclear material sample analysis [10]
- To investigate the needs for standards/reference materials supporting DA and NDA instrument metrology and conformity assessment and their application in estimation of measurement uncertainty
- To make recommendations on uncertainty in nuclear data in view of new approaches in safeguards
- To make recommendations for the validation of modelling codes
- To establish a priority ranking on required standards/reference materials, nuclear data and quality control tools
- To make recommendations for knowledge management/transfer and training in metrological concepts
- To identify areas for improvement
- To increase the understanding based on metrological principles and the GUM between different approaches in uncertainty estimation for DA, NDA and in the evaluation of reported results

Based on the discussions during the workshop, it was intended that recommendations on the topics listed above would be given. As a further result, the understanding of metrological principles and the GUM between different approaches in uncertainty estimation for DA, NDA and in the evaluation of reported results would be increased. A third aim of the workshop was to establish a priority ranking on required standards/reference materials, nuclear data and quality control tools. Since Euratom Safeguards very much supported this initiative of the three working groups, another goal was to share information on the work of the inspectors in the field carrying out independent verifications and assessing operators' measurement control programmes. The workshop provided an opportunity to learn about and discuss inspectors' metrological needs. Therefore the ESARDA working groups appreciated very much that Euratom Safeguards was hosting this dedicated workshop.

3. Workshop structure

Piotr Szymanski, Director: European Commission Directorate-General for Energy – Nuclear Safeguards (DGENER-E), gave the welcome address. This was followed by a short review of major issues and recommendations of the previous ESARDA WGDA *Workshop on Uncertainties in Nuclear Measurements*, held in Nov 2011 at the IAEA-SGAS [8]. One clear recommendation at that time was to pool efforts to ‘bridge the gap’ by organising a joint workshop DA and NDA.
Subsequently, the workshop objective, structure and practicalities were outlined to the participants. During three workshop days 26 presentations from workshop participants were given in one plenary and five topical sessions. The third day focused on the findings and points of discussion from these sessions and further discussions were held in a working group using the ‘World-Café’ approach around five selected topics. This approach ensured that all workshop participants could contribute to the discussion and benefit from the ‘collective intelligence’. The outcome of the discussions around the five selected topics was presented to all workshop participants and draft recommendations were agreed. The workshop was closed by the three WG chairs acknowledging DGENER for hosting the event and the contribution and lively exchange between the participants from the safeguards, operators, research and metrology communities.

3.1. Welcome address

In his welcome address, DGENER's Director-Nuclear Safeguards reminded the participants that nuclear safeguards conclusions are based to a large extent on comparison of measurement results. Reliability and comparability of measurement results is therefore crucial to the assurance of non-diversion of nuclear materials. This is directly linked to the importance of metrological concepts such as traceability and transparent measurement uncertainty for decisions in safeguards. Traceability of a measurement result is established via calibration standards and reference materials. For measurements of samples from all stages of the nuclear fuel cycle, a variety of nuclear reference materials are available. However, particularly for NDA, the non-availability of required standards for instrument calibration can be problematic and alternative approaches need to be investigated.
Furthermore, to achieve accurate measurement results and establish traceability, correct use of the reference material for a given measurement procedure is essential. Estimation of measurement uncertainties in a realistic, credible, and transparent way is crucial in order to base nuclear safeguards decisions on 'reasonable assurance'. The challenge lies in the quality and uncertainty of measurement results which translate (directly) into safeguards conclusions. The use of harmonised methods, developed and published in recognised international standards is advisable and important.
Piotr Szymanski emphasised DGENER-E's commitment to an integrated management system, including the application of the latest international standards: ISO/IEC9001, ISO/IEC 17020, ISO/IEC 17021, ISO/IEC 17025 [11, 12, 13, 14]. He emphasied that applying the latest international standards to conformity assessment is the means to underpin confidence in safeguards results and decisions. It is in this context that DGENER-E has identified a need for education and training in metrology and conformity assessment practices for the corps of inspectors. Therefore, DGENER has a major interest in facilitating the exchange between metrology institutes, measurement institutes, safeguards laboratories, operators, safeguards inspectors and evaluators, and appreciates the support from ESARDA and the participants in this workshop.

3.2. Plenary session

The plenary and first sessions were chaired by Petra Klumpp from DGENER-E, sector 1 Concepts, Planning and Evaluation of Inspections and addressed the three pillars of safeguards, inspections and evaluations for decision making in Euratom safeguards.

In the plenary lecture Oscar Alique from DGENER-E1 gave a comprehensive overview of safeguards verification activities arising from the legal requirements laid down in chapter VII of the EURATOM treaty. He used a graphic representation to illustrate the verification components: 'first layer assessment, physical verification activities and material balance evaluation and Nuclear Material Accounting and Control (NMAC) audit', to describe how declarations, which have to be submitted by a nuclear operator, are assessed and verified by the safeguards directorate. He reiterated that safeguards consisted of conformity assessment activities and concluded that the assessment of measurements and the assessment of the quality and fitness for purpose of measurement systems are indispensable to reach safeguards decisions. First and foremost, he highlighted the importance of the material balance evaluation exercise to draw meaningful safeguards conclusions.

3.3. Session 1: Safeguards - Inspections and Evaluations

Needs of the inspector in the field on "fit for purpose" measurement systems in compliance with latest international standards

Stefano Vaccaro from DGENER-E1 reported on the needs of inspectors in the field with respect to the characteristics of measurements and measurement systems to be 'fit for purpose' and compliant with latest international standards. He gave an overview of the normative framework applicable to measurements and measurement systems [7, 9, 14, 15, 16, 17, 18]. He illustrated his presentation with an example of an uncertainty estimation

based on the classic historic approach i.e. calculating standard deviation, versus the uncertainty model approach using the fishbone diagram. He concluded that a measurement or measurement system has to fulfil five criteria to be fit for purpose: the method has to be appropriate for the need; the method has to be validated; measurements must be traceable; the uncertainty calculation has to be adequate; and, last but not least, measurements have to be controlled. He concluded by calling on the experts and researchers for support in improving the metrological know-how on complex measurements used in safeguards.

Measurement model for material balance evaluation (including International Target Values for safeguards)

Claude Norman, from the IAEA Division of Information Management, Dept. of Safeguards, presented the IAEA's measurement model for material balance evaluation. She gave a comprehensive description of measurement errors and their sources and she explained the terminology applicable to measurement errors as applied in the IAEA's model for material balance evaluation. She introduced the additive statistical model of error and illustrated its components i.e. random error, short-term systematic error and bias with graphic representation. She displayed the behaviour of error components over time and described the multiplicative model used by the IAEA in order to use Relative Standard Deviations (RSB) stored in databases. She put the 'measurement error estimation' into the historic context by describing the development of the ITV as the intention to determine uncertainties in a coherent fashion for a multitude of measurement methods and material types employing ‘historic operator – inspector paired data’ and applying QC/QA experience at an international level.

Measurement as an essential component of nuclear safeguards: Nuclear safeguards inspectorates needs regarding measurements

Oscar Alique gave a presentation on the role of measurements as an essential component of nuclear safeguards from a EURATOM perspective. He outlined the legal requirements, the characteristics of nuclear operators’ NMAC systems and related Measurement Control Program (MCP), and he explained how flow and inventory verifications serve to draw meaningful safeguards conclusions. Based on latest international standards he illustrated the components of the first layer assessments, the physical verification activities and the material balance evaluation paired with NMAC audit. He gave an overview of measurement needs and described the instruments for enforcement, i.e. regulation EURATOM 302/2005 and the verification agreements. He placed particular importance on assessing the quality and fitness for purpose of the nuclear operator's measurement system and NMAC system.

The SRD (Shipper receiver difference). A challenge for evaluators

Session one finished with a presentation on the challenges arising from SRD (Shipper receiver difference) by Raffaele Bencardino from DGENER-E2. He gave a summary of definitions to indicate that SRD detection and evaluation serve to detect clerical errors, measurement errors, loss or theft, misstatement or diversion. He used the analogy of a bank account to explain effects of shipments and receipts represented as transfers and discrepancies (material unaccounted for - MUF) represented as charges or interest. He described the approach to the null hypothesis for testing statistically significant SRD requiring further investigation. He illustrated the need for operators to comply with latest international standards to mitigate the challenges. He referred to traceability to SI and explained the challenges arising from: the traceability to different reference samples of the measurements performed by the shipper and the receiver; the analysis of losses or understatement in the context of a material balance evaluation exercise; and the detection of accountancy practices intended as MUF tuners e.g. by declaring measured discards or transfers to waste. He concluded that SRD poses challenges, requires traceability and still is hardly detectable if not declared explicitly or masked e.g. by the use of accountancy codes such as Deletion/ Addition of accountancy lines (D/A) or New Measurement (NM) instead of SRD.

3.4. Session 2: Destructive Analysis

The second session, chaired by Evelyn Zuleger from EC-JRC-ITU, was dedicated to destructive analysis and, in particular, to needs in development of future reference materials.

Summary of WGDA WS on uncertainties in nuclear measurements (recommendations)

The session started with a summary given by Yetunde Aregbe (EC-JRC-IRMM) on the previous workshop organised by the ESARDA WGDA on “Uncertainties in Nuclear Measurements", hosted by the IAEA-SGAS, held on 8-9 Nov 2011, Seibersdorf. The objectives, sessions and recommendations of the workshop can be found in the respective report [8]. This presentation put the focus on the follow-up of the main recommendations from that WGDA workshop. It was quite remarkable to see that within less than 1 ½ years all main recommendations have been addressed in one way or the other. (One recommendation was to organise a joint DA and NDA workshop !) Reference material providers such as EC-JRC-IRMM and NBL have seriously engaged in cooperation with other US-DOE and CEA laboratories to make reference materials - of uranium, plutonium, americium and thorium - and Interlaboratory Comparison (ILC) schemes available in the near future for determining the origin and age of nuclear material. Furthermore, i.e. efforts towards uranium particle reference materials are undertaken including a new support task to the IAEA on Production of Particle Reference Materials [19, 20, 21]. Recently the IAEA produced and characterised plutonium dioxide particles as a quality control material for Pu-Am age-dating [22]. In response to the re-occurring need for 'fit-for-purpose criteria', the IAEA has issued an internal document on 'Measurement Quality Goals for the bulk analysis of environmental samples', requiring harmonised measurement result reporting with relative expanded uncertainties from their Network of Analytical Laboratories (NWAL). An example of the value of GUM to estimate measurement uncertainty is the EC-JRC-IRMM IRMM thorough validation study for accurate UF_6 isotopic measurements using the "URANUS“ gas source mass spectrometer (GSMS) [23]. In line with the recommendations of the ESARDA WGDA workshop to facilitate technical exchange between safeguards, industry and instrument developers, EC-JRC-IRMM hosted in May 2012 the first 'UF_6 user group meeting' with participants from Urenco (Gronau/German, Almelo/Netherlands), Enritech (Jülich/Germany), Thermo Fisher (Bremen/Germany), IPEN (Sao Paolo/Brazil) and the IAEA-SGAS (Seibersdorf/Austria). As a result of this successful exchange between safeguards, reference institutes and industry, EC-JRC-IRMM and NBL were invited to write a new ASTM standard on Modified Total Evaporation Thermal Ionisation Mass Spectrometry (MTE-TIMS) and revise existing uranium measurement standards with the ASTM Committee C26 on Nuclear Fuel Cycle after participation in the ASTM meeting in June 2013, Avignon [24]. Furthermore, training modules for chemical and ionising radiation metrology have been developed (see also section 3.7).

Using the GUM approach to estimate measurement uncertainty - time & effort vs. benefit

Stefan Bürger from the IAEA-SGAS started his presentation with examples of published results over 4 decades for the half-life of ^{241}Pu, to illustrate that it is challenging to judge whether measurement results agree and/or are comparable without a reliable estimate of their associated measurement uncertainties. The beauty of the GUM is to represent a standardised way of expressing uncertainty in measurement, consistent with establishing metrological traceability, e. g. to the International System of Units (SI). This to ensure that results are truly comparable [9]. Furthermore, the GUM in combination with the International Vocabulary of Metrology (VIM) enables a common 'metrological language' across measurement communities and uncertainty evaluation approaches via specific terminology [25]. GUM provides a step-by-step approach starting with the definition of the measurand (quantity that is intended to be measured); identifying and quantifying the sources of uncertainty associated with the analytical procedure, building a mathematical model, calculating the combined standard uncertainty and finally to state the expanded uncertainty (for a desired level of confidence) of the measurand. One of the benefits of this

methodology is the resulting uncertainty budget and that it is transparent and can be reproduced by others. In contrast to classical error analysis, the GUM approach requires that the measurand is corrected for all recognized significant systematic effects, resulting in a single value for the combined standard uncertainty. At the same time the GUM allows estimation of standard uncertainties of input quantities evaluated by scientific judgement (Type B evaluation of standard uncertainty). As an illustration, the result of a GUM uncertainty evaluation of a ^{235}U analysis by mass spectrometry was discussed [26]. To achieve a balance between effort versus benefit, it is advisable to design an analytical procedure with a GUM uncertainty evaluation in mind right from the beginning.

Harmonised approach CEA-AREVA in uncertainty estimation for isotope measurements in nuclear samples

Guy Granier, from CEA/CETAMA Marcoule, France [27], presented on behalf of the CETAMA Working group 12 (GT12) on mass spectrometric measurements, the harmonised approach of CEA-AREVA. He gave an overview of the CEA/DAM (military applications) and CEA/DEN (nuclear energy) laboratories, as well as a list of the AREVA laboratories (FBFC Roman, MELOX S.A, AREVA NC, La Hague, AREVA NC, Marcoule) and the different types of samples and measurements that are carried out (fuel, mass balance assessment, reprocessing, environmental). At the request of these laboratories, the sub-group on isotopic analysis of the CETAMA GT12 started to draft a guideline to harmonise the assessment of uncertainty in Thermal Ionisation Mass Spectrometry (TIMS) of uranium samples. The approach was first to establish an inventory across the group of laboratories on sample types, sample preparation, TIMS instruments and applied measurement protocols. During this process, it was discovered that the type of filaments plays a crucial role for the final uncertainty of TIMS measurements. As a consequence, collaboration with the filament manufacturer resulted in the provision of rhenium filaments of higher purity. The first part of this guideline for laboratories to evaluate the combined standard uncertainty of their measurement results is close to completion. It is based on reports, publications in the open literature and in line with the GUM. In parallel, an excel sheet is under development to help the laboratories to identify the major contributions to the overall uncertainty of the measurement. Furthermore, Interlaboratory comparisons (ILCs) using uranium reference materials provide external evaluation within the limits as given by the ITV. This is once more an illustrative example on how measurement results can improve when the communication channels between nuclear laboratories, operators and manufacturers are properly established. As a spin-off via publishing a guideline, a laboratories exchange forum on reference materials was established with industry and instrument manufacturers on particular procedures and instrument combination.

The analysis of environmental samples for safeguards at CEA/DIF: methodology and need for CRMs

Anne-Laure Faure, CEA / DAM Ile de France, focused in her presentation on needs for reference materials for environmental sample analysis. She recalled the challenge of detection of undeclared material/activity without direct access to the nuclear material or to the specific facility in which the nuclear material is treated or stored. This led to the development of highly sensitive methods to detect and characterise the nuclear signatures in environmental samples. Two current approaches are the bulk and the particle analysis of environmental swipe samples taken by safeguards inspectors. For bulk analysis, the cotton cloths are dissolved after spiking with ^{233}U and ^{242}Pu and then the uranium is separated from the plutonium and analysed by ICP-MS. A significant contribution to the combined uncertainty comes from the uncertainty of the spike CRM. Particularly high purity and well-characterised ^{242}Pu and ^{244}Pu tracers are needed. Furthermore, quality control swipes and environmental CRMs with low amounts of actinides (Pu, Am) would be needed for method validation. For particle analysis, Fission-Track Thermal Ionisation Mass Spectrometry (FT-TIMS) and Secondary Ion Mass Spectrometry (SIMS) are used by a number of laboratories, whilst CEA-DIF also uses the alternative technique of Laser Ablation Multi-Collector Inductively-Coupled Plasma Mass Spectrometry (LS-MC-ICPMS. There is a need for uranium and plutonium reference particles characteristic of various stages o the fuel cycle (UO_3, UO_2, U_3O_8), especially uranium oxyfluoride (UO_2F_2) particles

as a representative signature for conversion/enrichment processes. Particle reference materials should be certified for mass, isotopic composition and chemical composition. The techniques mentioned above are also used in nuclear security applications to obtain information on the use, the origin and the processes undergone by seized nuclear material. To this end, certified bulk and particle uranium and plutonium materials should be developed for 'age dating'. Uranium, certified for the last separation date of both ^{234}U (from ^{230}Th) and ^{235}U (from ^{231}Pa), and uranium ore concentrate (UOC), certified for uranium and oxygen isotopic composition and for impurities (Rare Earths Elements), is needed. CEA/DIF is currently participating in the characterisation of a ^{229}Th spike in collaboration with US-DOE laboratories.

Availability and priorities on certified reference materials (CRMs) for the estimation of measurement uncertainty in material accountancy and environmental sample analysis

Since January 2013 the EC-JRC-IRMM is operating under a quality system, in compliance with ISO 14001:2004, ISO 9001:2008, OHSAS 18001:2007, ISO 17025:2005, ISO Guide 34:2009 and ISO 17043:2010 at institute level [28, 11, 29, 14, 30, 31]. IRMM as accredited provider of reference materials has a whole range of isotopic and spike nuclear reference materials available [32]. Rožle Jakopič gave an overview of the currently available IRMM reference materials, describing in more detail the preparation of the IRMM-1027 series, commonly known as Large-Sized Dried (LSD) spikes. They are prepared from high purity metals (MP2, EC 101, CRM 116), certified for masses of ^{235}U, ^{238}U, ^{239}Pu, and U and Pu amount ratios per unit. The spikes are a fundamental part of the fissile material accountancy of irradiated nuclear fuel and are applied to measure the uranium and plutonium content of dissolved nuclear fuel solutions using isotope dilution mass-spectrometry (IDMS) at the EURATOM safeguards on-site laboratories at Sellafield, UK, and La Hague, France. In this context, it is important that CEA/CETAMA and NBL can guarantee the supply of MP2 and the new uranium metal CRM116-A to the community for the coming years. Nevertheless, these base materials should only be used when absolutely necessary, as they are precious materials. It could be considered to use certified oxides as base material for LSD production as an alternative. A new certificate for IRMM-042a (^{244}Pu spike) and a new IRMM-046c (mixed ^{233}U/^{242}Pu spike) will be released this year. The preparation of a new IRMM-049e (^{242}Pu spike), replacing the very popular IRMM-049d, will be undertaken in 2014 and a new certificate for IRMM-086 (^{239}Pu) spike as part of the ongoing Pu inter-calibration exercise to demonstrate long-term stability of IRMM spikes will be issued [33]. Recently, IRMM launched a CRM project to use the TIMS modified total evaporation (MTE) technique to issue new certified values for basic IRMM UF_6 reference materials such as the frequently used IRMM-019-029 series. Close cooperation was established with EC-JRC-ITU to provide the nuclear forensics and nuclear safeguards community with reference materials certified for 'age'. 'Age' in that sense is defined as the time that has passed since the last chemical separation of the mother and daughter isotopes. A feasibility study towards a Pu CRM for age dating is currently ongoing [34]. IRMM-1000, a uranium reference material certified for the date of the chemical separation of thorium from uranium (^{234}U/^{230}Th), has been prepared by ITU and IRMM. Before the release of this new reference material, part of the units are be used for the ILC REIMEP-22 [35]. It is currently under investigation whether a CRM project on the preparation of a ^{243}Am spike can be undertaken in the near future.

New materials and refined attribute values for safeguards and nuclear forensics CRMs

The last presentation in this session was given by Richard Essex, New Brunswick Laboratory, giving an update on the US-DOE NBLs status and CRM production. Since Dec. 2012, Dr. Steven Bakhtiar is the new Director of NBL. The uranium laboratory is fully operational again and the UF_6 laboratory is in testing qualification. The Pu facilities are in initial startup. A complete list of NBL reference materials can be found in [36]. NBL is currently preparing CRM-115 (0.2% ^{235}U depleted metal) and CRM 116-A (93% ^{235}U enriched metal), urgently needed by the nuclear community. 500 units of CRM 116-A of 1.1g have been produced: the homogeneity has been assessed; packing and

characterisation are in progress. CRMs with limited availability are CRM 111 (99.92% ^{233}U enriched) and CRM 131 (97.89% ^{244}Pu enriched) spike materials. NBL is using some of their existing CRMs and certifying them for additional properties. For instance CRM-125A (^{235}U enriched UO_2 pellets) and U630 (^{235}U enriched U_3O_8 oxide) will be certified for 'apparent' last separation date, to be used as U/Th chronometer with an uncertainty of about +/- 0.5 years. CRM U045 (4.5% ^{235}U enriched) uranyl nitrate solution will be in addition certified for $n(^{233}U)/n(^{235}U)$ and $n(^{232}U)/n(^{235}U)$. NBL will characterise an existing NIST stock material to produce a ^{229}Th spike (99.9%). The problem is that the ^{229}Th half-life is poorly known. In cooperation with the National Physical Laboratory, a ^{243}Am (99.9%) spike will be produced. Some of these spike materials are primarily for domestic use, but a few units can be made available in the frame of international cooperation projects. Other potential CRM projects at NBL are trace actinides in U and Pu, trace elements in U and Pu, ultra-high purity ^{233}U tracer solution, >99.99%, and uranium synthetic calibration mixtures.

3.5. Session 3: Non-Destructive Analysis

The third session, chaired by Johan Dackner from DGENER-E, was dedicated to non-destructive measurements.. In this session, the first four presentations dealt with current approaches to estimate measurement uncertainties in NDA, notably the GUM. The subsequent four presentations addressed the availability and future needs for standards/reference materials supporting NDA instrument metrology and conformity, as well as alternative solutions developed to reduce the need for those standards.

Method validation and evaluation of measurement uncertainty

Anne-Laure Weber from IRSN illustrated, using uranium mass measurement by high resolution gamma spectrometry, the methodology implemented by IRSN to evaluate the measurement uncertainty and validate a non-destructive measurement method on a defined application range. The measurement method consists of measuring the apparent mass of uranium at several gamma energies and correcting it for matrix attenuation by a gamma scanning and for uranium self-absorption by extrapolating the apparent mass to the infinite energy. The sources of errors come from the sample (counting statistics, uranium isotopic composition, self-absorption by uranium), self-attenuation (by materials others than uranium), geometry, nuclear data, the detector and its electronics (measurement distance, detection efficiency, pile-up effects), and the environment (background).The approach used to determine the sources of error and to quantify each uncertainty component, based on the GUM (type A and type B methods), was illustrated in detail in the talk. Validation of the measurement uncertainty using certified reference materials was presented. As a result of the qualification and the validation process, a measurement uncertainty and a scope of applicability have been defined for domestic safeguards verifications [37]. Such an approach takes time, requires the use of CRMs and a certain number of experiments, but mastery of the measurement uncertainty is of high importance for conformity assessment application.

Uncertainties in Active Well Coincidence Counter (AWCC)

Paolo Peerani described the experimental and statistical approach implemented by the EC-JRC-ITU to evaluate the pertinence of the uncertainties reported in the final protocol of an active neutron measurement of the mass of ^{235}U. The measurement method consists of interrogating a uranium sample with a neutron source in order to obtain the induced fission response of ^{235}U, and applying a calibration curve which links the induced fission response to the ^{235}U mass. The uncertainties reported in the final protocol (International Neutron Coincidence Counting software-INCC) consider a component derived from counting statistics and a component related to the calibration model (fit compared to the experimental points). A first experimental study consisted of evaluating the behaviour of the relative uncertainty on the experimental response first, and then on the associated ^{235}U mass, according to the ^{235}U mass for several measurement times. It showed that the evolution of the assay mass relative error was dependent upon two competing competitive effects: type A errors for low ^{235}U content: type B errors for high ^{235}U content. The

distribution of the (declared-measured) values was shown to be broader than the normal distribution, indicating an underestimation of the measurement uncertainty. The unaccounted source of error was estimated to come from sample positioning, sample characteristics (density and shape of powder) and impurities. An alternative approach was considered using an error propagation method with a constant (unknown) additional variance, computed by minimizing the χ^2 value, taking into account the unaccounted sources of error. The calibration curves were re-computed and the re-evaluation of the verification measurements indicated a more accurate evaluation of the uncertainty, highlighting the importance of an accurate statistical treatment.

Error estimation in nuclear material weighing

Bernard Thaurel from IRSN gave a presentation on the factors influencing a weighing result, showing that weighing is not as simple an operation as it is a priori considered. Weighing is usually used within fuel cycle facilities in association with concentration measurements to quantify nuclear materials. The required performance of the weighing system must be defined by the operator, depending on the final objective, on a three parameters basis: the measurand, the technical specifications required and the normative and contextual constraints [38]. A weighing result should be presented in terms of real mass (physical, constant and intrinsic data characterizing the object). But it can also be expressed in terms of apparent mass (weighing carried out in atmosphere is sensitive to gravity and Archimede's buoyancy) or conventional mass (mass of a fictitious standard of density 8000 kg/m^3 that balances its body under conditions conventionally chosen). For instance, a uranium nitrate solution (1400 kg/m^3) of 1000 g (real mass) will have an apparent mass of 999,14g and a conventional mass of 999.29 g. The terminology has to be carefully taken into consideration. Many factors have to be taken into account by an operator to reach the desired relative uncertainty (usually $\geq 10^{-4}$). The influencing factors can be split into five categories: the measurand; the environment; the equipment; the operator; and the method. Three factors need to be considered in priority: the intrinsic performance of the instrument; the environmental conditions of calibration and current use; and the physicochemical form of weighed products. The balance performance, expressed in terms of resolution, sensitivity, fidelity, eccentricity limits and linearity' affects the measurement uncertainty. It is necessary to use standards correlated to international standards (traceability) to adjust, calibrate and check balances. The environmental conditions directly impact the balance sensor and the air density, so the air temperature, barometric pressure and air humidity should be stable during the measurement. The balance measures a force induced by the weighed body. Consequently, its indication depends on the local gravity, which needs to be corrected. Concerning the measurand, the temperature (air buoyancy correction), the density (the air buoyancy correction depends on an equivalent density for the whole body, i.e. container, nuclear material, air), the tare of the container (impact when measuring gas such as UF_6 containers with some of them empty and others filled with air) and the magnetization of the container have to be considered.

Uncertainty case studies in radionuclide metrology

Stefaan Pommé's (EC-JRC-IRMM) presentation dealt with the control of measurement uncertainties, which is essential for drawing appropriate conclusions from a measurement. He started his talk by providing general thoughts about the GUM [9] approach and the pitfalls to avoid when estimating measurement uncertainties, and illustrated these thoughts with the example of half-life measurements. The GUM approach is shown as a step by step methodology starting with the modelling of the measurement in order to understand the process, followed by an active search of the uncertainty components, a proper propagation of the uncertainty components in order to estimate the standard combined uncertainty and finally a detailed report of the uncertainty budget. A comprehensive uncertainty budget, quantifying unknowns to the best of our ability, and the traceability of measurement results is a prerequisite for future improvements and amendments. The typically-encountered pitfalls are the following:

- Omission of uncertainty components, particularly the systematic components that are not well understood → repeatability is not enough, the bias need to be investigated too (too small uncertainties usually indicate a lack of knowledge)
- Underestimation of uncertainty components, by relying on “black boxes” (software, fits, certificates, manuals) → scrutiny is needed: the less we know for sure, the higher the uncertainty should be
- Modelling not representing reality to the fullest extent (fitting mathematical functions to measurement data, spectral deconvolutions) → awareness and quantification needed
- Complication of uncertainty budget, e.g. by using big master equations that look complicated, but do not tell the whole story → simplification is recommended by subdividing into factors.

The GUM divides the uncertainties into two categories: type A category obtained from the width of an observed frequency distribution (mean and variance from repeated measurements) and type B category founded on a priori distribution. Type A approach needs to be carefully considered, as it is blind for uncertainty components that do not reveal themselves in variance (systematic errors). An unawareness of bias leads to an underestimation of the uncertainty. The GUM recommends an expression of the combined standard uncertainty, which is convenient in the sense that the propagation properties are independent of the statistical distributions of the variables, as our knowledge of these distributions makes our results directly usable by others.
Studying the example of half-lives, it is obvious that data published in literature show discrepancies, which indicates that the uncertainties are often underestimated. Consequently, uncertainties of derived quantities are underestimated, which can lead to erroneous decisions. Half-life measurement is a good example as it implies background subtraction, deconvolution of spectral interferences, variations in efficiency, correlations and imperfections of modelling. The model of exponential decay is incomplete, as it does not include instabilities or interferences. Moreover, residuals of fit should ideally be only random by nature. In reality, the influence of seasonal effects is underestimated and slow variations are compensated by fit and thus hidden. Stefaan Pommé stressed the fact that we need to be careful when fitting a model: fitted parameters are only meaningful if the fit function rigorously applies to the data. Moreover, common statistical tests require randomness of data. They do not apply to auto-correlated data. The uncertainty derived from a fit is unreliable if these conditions are not fulfilled.

Gamma-ray spectrometry : from measurement to metrology

Marie-Christine Lépy from LNHB highlighted in her presentation the need for reference standards when using gamma-ray spectrometry for activity measurement or photon emission intensity measurement, and discussed the possible alternatives, focusing on Monte Carlo simulations. Gamma-ray spectrometry is a relative method that requires the experimental calibration of the detector efficiency using standard sources. Efficiency calibration is a major issue which needs to be carefully established. An experimental calibration of the detection efficiency according to the energy in the range 10 to 130 keV indicates both a lack of nuclides in the region 50 to 150 keV, and an inconsistency of some data. An international working group gathering 20 evaluators from 10 reference metrological laboratories was established in 1995 (Decay Data Evaluation Project) to evaluate and provide carefully recommended data characteristics of the nuclear decay [39, 40]. The DDEP evaluated data were approved by the International Committee for radionuclide Metrology to be used for future nuclear data studies. They are compiled and edited by the LNHB [41]. New developments such as magnetic metallic calorimetry help in improving the knowledge of photon emission intensities. Detector efficiency calibration can also be obtained using Monte Carlo simulation, generating spectra for any source of detector geometry. Each photon is followed along its path from its origin in the source up to its absorption within the source itself, the detector or the measurement environment. The secondary generated particles, such as electrons or X-rays, are also simulated. Monte Carlo simulations offer the possibility to describe accurately complex geometries in three dimensions, and consider all physical processes. But it is time consuming, it requires an accurate knowledge of some geometrical parameters (especially inside the detector), and the uncertainties associated with interaction cross sections are not taken into account. An

inter-comparison exercise of Monte Carlo codes used in high resolution gamma-ray spectrometry was organized in 2008, by the gamma spectrometry working group of the International Committee for Radionuclide Metrology, in order to assess the performance of Monte Carlo simulations of full energy peak and total efficiency, considering different sample-detector arrangements [42]. Three configurations were simulated: a bare HPGe crystal with a point source; a p-type HPGe detector with a point source; and a p-type HPGe detector with an extended source. Six Monte Carlo codes were used by the participants: GEANT, EGS, MCNP, PENELOPE, GESPECOR and TRIPOLI. The exercise showed that Monte Carlo simulation alone is hazardous for absolute efficiency calibration and that it requires comparison with experimental values. Moreover, in some cases the reported uncertainties comprised a statistical component only. In the end, it was recommended to use Monte Carlo simulation for efficiency transfer, and to respect the same experimental conditions between the efficiency calibration and the item measurement, in order not to increase the total uncertainty. As general remarks on gamma spectrometry measurements, Marie-Christine Lépy highlighted that traceable measurements require reference to national standards, that the uncertainty budget should not forget a basic check on the instrument performance and should be sufficiently detailed to enable further processing of the results (noting that careful consideration of the measurement process and associated uncertainties generally leads to an increase in the final combined uncertainty). It was also recommended not to use too many digits when reporting results, having in mind that the relative uncertainty on the uncertainty is about 30%.

Calibration of NDA systems – a complementary approach of RMs and modelling

Paolo Peerani's (EC-JRC-ITU) presentation dealt with computational calibration as a means to reduce substantially the need for standard reference materials to calibrate NDA instruments: indeed, a means to replace calibration. The response of NDA instruments is strongly dependent on the sample characteristics, which requires an experimental calibration performed with reference materials having characteristics as close as possible to the measured item. In reality, such relevant standards might not always be available. Thus computational calibration can fill the gap. The recognized MCNP code, which allows the simulation of the transport of neutron, photons and electrons in three dimensional geometries by Monte Carlo method, has been adapted by JRC-ITU to predict the response function of active and passive neutron coincidence and multiplicity counters. The so-called MCNP-PTA enables computation on a normal PC of the total neutron count rate in a few seconds and the coincident neutron count rate in 10 to 30 minutes with a typical difference between calculation and experiment of a few percent.. Nevertheless, the Monte Carlo models of NDA instruments need to be validated through an extensive comparison of calculations versus measurements using reference materials. A full numerical calibration application was presented in the case of non-availability of representative standards [43]. The procedure implemented for this purpose included a campaign of measurements with reference materials showing that, if computational calibration can reduce the need for standard reference materials, computation cannot totally replace them. Could the solution be a change of paradigm to replace calibration? Paolo Peerani presented an alternative approach to calibration consisting of using real time simulation to compute, with MCNP-PTA, the response function of an active or passive neutron coincidence counter to the sample whose mass has to be verified, and comparing the simulated count rates to the measured count rates instead of comparing the declared mass to the measured mass. Considering that neutron coincidence counting measurements are done using sources with intensities in the range of 30000 to 100000 neutrons per second, and that an ordinary laptop runs 5000 to 8000 neutron histories per second, a performing workstation could run Monte Carlo as fast, indeed faster, than the actual measurement. This makes the concept perfectly conceivable.

Reference material needs in support of the IAEA's NDA measurements (C. Norman– IAEA SGIM-IFC)

Claude Norman, from the IAEA Division of Information Management, Dept. of Safeguards, presented, on behalf of her colleagues Stephan Jung and Andriy Berlizov, the IAEA needs for reference materials in support of R&D, testing, validation and authorization of new NDA instruments and measurement techniques, calibration and training.
Concerning neutron techniques, a non-multiplying ^{240}Pu reference metal sample; long-lived spontaneous fission neutron reference sources (Cm); and an extended set of low enriched uranium fuel pins would be useful for measurement parameters setting (^{240}Pu); providing long-term stability to the IAEA's ability to adequately characterise neutron sources (Cm); and improving calibration of uranium neutron coincidence collars for LEU fuel assemblies assay and enhancing related training capabilities.
Concerning gamma techniques, infinitely thick reprocessed uranium standards and high enriched uranium standards would be beneficial to test and calibrate the enrichment meter method. The system COMPUCEA (Combined Procedure for Uranium Concentration and Enrichment Assay) would need to be calibrated with 2% and 20% enriched uranium in addition to the existing 4% enriched CRM-125 pellets. Finally, the organisation of an inter-comparison exercise on performance assessment of Pu isotopic abundance and mass assay techniques based on medium resolution gamma-ray spectrometry requires a set of 9 Pu and 9 MOX isotopic and mass standards (3 masses x 3 burnups). It was also mentioned that a variety of dual-use materials, mostly non-nuclear and non-radioactive materials, would be of potential interest in order to adapt instruments to the detection and the identification of nuclear fuel cycle indicators. These materials would also serve as reference standards to ensure the correctness of material identification and interpretation of on-site measurements. The list of materials is currently under elaboration. Claude Norman presented well defined needs for reference materials to NDA instrument metrology. Additional reference material issues were addressed within the NDA WG. They concerned Pu (down to low level waste levels), MOX, U and ^{238}U calibration standards. Source issues also exist, such as the supply of AmLi sources required for some active neutron systems (use of AmBe as alternative). There is an interest in using ^{252}Cf reference standards for both calibration (impurity analysis of ^{250}Cf) and cross-calibration against reference Pu standards (minimizing the need for transporting Pu sources between facilities), in addition to working standards for quality assurance purposes. The consideration of ^{244}Cm as an alternative to ^{252}Cf or the limited availability of pure even-isotope standards, which are of interest to allow measurement of nuclear data or to improve the accuracy of modelling for exotic fuels was also mentioned. It was clear that these issues need to be further addressed.

Uncertainties - approaches for modelling

Paolo Peerani (EC-JRC-ITU) gave, on behalf of Patrick Chard from AREVA/Canberra, a presentation on the procedures to implement and assess the accuracy and evaluate the uncertainties associated with numerical simulations of NDA measurements. As already indicated in previous talks, numerical simulations are used in safeguards applications for detector design studies and system optimization, characterization of nuclear reference material for self-shielding and self-multiplication, and direct calibrations of NDA systems. Two families of codes can be distinguished: Monte Carlo codes for neutron and photon transport, and discrete ordinates ray tracing. The presentation highlighted the importance of benchmarking simulations versus measurements in order to establish the accuracy of the predictions. The ESARDA NDA WG organized four benchmarks in the last 15 years, in order to assess the state of performance of both codes and interpretational models to simulate the response of neutron coincidence counting techniques. The first benchmark exercise addressed Monte Carlo predictions of neutron coincidences count rate. The second addressed a simple case in order to establish fundamental limitations of accuracy for Monte Carlo modelling, focusing on the sources of uncertainty (physics, modelling, nuclear data). The third aimed at comparing and harmonizing modelling techniques for multiplicity counters, based on theoretical point model data and the most recent was a follow-up to the third exercise, considering real source measurements. Gathering the feedback from these exercises, the NDA WG edited a good practice guide for the use of

modelling codes in non-destructive assay of nuclear materials. The guide addresses issues related to problem definition, validation, training, quality assurance, nuclear data, physics treatment and uncertainties [43]. A typical MCNP procedure for calibrating a passive neutron multiplicity counter was then reviewed. It consists of establishing a design model, performing a benchmark experiment on detection efficiency and parameters of interest for the coincidences (die-away time, nuclear data, etc), refining the model until good agreement is reached, developing and running models for a range of sample types and finally calculating the response function throughout calibration range of sample properties.
The last part of the talk focused on the origin of modelling uncertainties. The first component comes from stochastic effects, which decrease when increasing the number of source particles. The convergence of the calculation also needs to be checked (the codes usually run statistical tests). Nuclear data are the second source of uncertainties. Their impact can be quantified using benchmark problems. The user then needs to evaluate how close the model reproduces the measured response by benchmarking it against real measurements, and eventually apply a systematic correction. The geometry uncertainties can be considered as combined systematic uncertainties, taken into account in the benchmark correction factor, but their consistency need to be verified through the calibration dynamic range. Sensitivity studies can also be performed to assess the impact of environmental or physicochemical parameters. Variance reduction techniques can be used in order to speed up the calculation. The techniques should be validated to ensure that there is no bias. Finally, the interpretational models can also introduce biases. Benchmark exercises will allow demonstrating analysis techniques to convert calculated tallies into count rate quantities.

Benchmarking and evaluation of codes

Pierre Funk described the methodology implemented at IRSN, France, to test, evaluate and validate the new version of gamma-ray isotopic analysis software compared to the previous version, with the objective of reducing the time needed for such assessment while improving efficiency. The first step consisted of selecting a reference dataset of uranium, plutonium and MOX spectra that cover as many situations as possible. The spectra within the database were acquired from reference materials certified for plutonium isotopic composition and uranium enrichment available in the IRSN's safeguards laboratory or coming from inter-comparison exercises. In a second step, an automatic tool was developed in order to analyze this dataset with a different software version for Pu-isotopic abundance and U-enrichment compared to the previous version. Finally, the comparison of the two versions was performed by calculating performance ratings. The performance rating uses both the measurement error, defined as the difference between the measured and the reference value, and the measurement uncertainty, which characterises the range for the true value and is given by the code. Each measurement is scored, considering that in an ideal situation (1) the uncertainty given by the code would correctly evaluate the error really committed on the true value and (2) both error and uncertainty would be small for an accurate result. The scores go from -2 for a measurement having a large error (greater than a first threshold "z") and an uncertainty poorly evaluated (i.e. an absolute value of the difference between the relative error and the relative uncertainty greater than a second threshold "t") up to 6 for a measurement having a small error (lower than a third threshold "x") and an uncertainty correctly evaluated (i.e. an absolute value of the difference between the relative error and the relative uncertainty lower than a fourth threshold "y"). A global performance rating is obtained for each database by calculating the mean value obtained over the whole spectra database. One way to define the thresholds consists of considering that an error is small when it is less than "x" for at least 70% of the number of spectra constituting the database, and an uncertainty is properly estimated when the absolute value of the difference between error and uncertainty is less that "y" for at least 70% of the number of spectra constituting the database. Consequently, the thresholds "z" and "t" are taken to be equal to three times "x" and "y". Thus the methodology allows an evaluation based on a global approach. It can be applied to validate a new version of a code, to cross-compare codes, and can be generalized to any kind of measurement.

3.6. Session 4: Novel Technologies

The fourth session, chaired by Harri Toivonen from STUK, Finland, was associated with measurements and needs for reference materials towards novel technologies for future application in safeguards.

Uncertainties in nuclear data

Stanislav Simakov from the IAEA *Nuclear Data Section* gave a presentation on the activities of the Nuclear Data Section relevant to safeguards. The basic nuclear data information is collected in the IAEA Handbook of Nuclear Data for Safeguards [44]. The status and uncertainties of nuclear data were reviewed for several operational NDA and novel techniques: gamma-ray spectroscopy, neutron correlation, self- and active-interrogation neutron resonance densitometry and nuclear resonance fluorescence. Often, the uncertainty of nuclear data used in such applications is of the order of a few percent or even less (gamma ray intensities, resonances cross sections, half-lives) and is not a major contribution to the total methodological accuracy. However, the nuclear data used in some NDA absolute methods are still scarce, have large uncertainties or are spread (neutron multiplicity distribution, spontaneous fission half lives, neutron resonance cross sections for fission products, (α,n) yields, NRF). Reaching the target accuracy for safeguards purposes will require improving the quality of such nuclear data

Uncertainty of conversion electron yields and its implication to spectrum analysis

Kari Peräjärvi from STUK, Finland, introduced a novel DA measurement technique based on conversion electronics. This approach has potential importance for isotope ratio measurements because conversion electrons are isotope-specific signatures whereas X-rays are element-specific. A small silicon-drift-detector (SDD) has a good enough energy resolution for the analysis of the $^{240}Pu/^{239}Pu$ atom ratio. Tests with a considerably larger area SDD, and also tests where the detector signal is split into two parallel amplifiers, are planned. The first amplifier would have low gain (alpha particles) and the second one high gain (conversion electrons and X-rays). There are two major problems that need to be solved before the operational usage of conversion electron spectrometry is possible:

1. Yields of the most important conversion electron transitions need to be studied using pure reference samples
2. Analysis software must be developed to take into account the non-Gaussian peak shapes and simultaneous presence of ordinary gamma rays and X-rays.

Uncertainties of correlated variables - example to alpha spectrometry

Harri Toivonen gave a presentation on the importance of correlated variables to combined uncertainty. If the correlation is not taken into account properly, the uncertainty may be seriously underestimated. A good example is the $^{239}Pu/(^{239}Pu+^{240}Pu)$ isotope ratio analysis using alpha spectrometry. The major peaks in the measured spectra are overlapping, i.e., in the fitting process they compete from the same counts. . A small error in analysis in favour of one nuclide, gives fewer counts to the other nuclide. This is a negative correlation and must be taken into account properly. Software, based on fitting and covariance analysis, has been recently developed in STUK. Detailed performance studies of the software, known as ADAM – Advanced Deconvolution of Alpha Multiplets, have shown that indeed a reliable isotope ratio analysis is possible with combined uncertainty of the order of a few percent [45]. Harri Toivonen suggested that, in general, the safeguards community should require better software for the calculation of uncertainty in a transparent manner. Fitting should be performed correctly, providing uncertainty estimates directly from the analysis process through covariance calculus. The analysis software should be validated by a simple data set with varying statistical properties. For example, a large set of spectra with one peak on a linear baseline could be generated by Monte Carlo. It should be required that the software gives correct results, including uncertainties, and then more complex validation would be performed using reference materials.

3.7. Session 5: Training on metrological concepts

The fifth session, chaired by Anne-Laure Weber from IRSN, France, was dedicated to an exchange on the needs for training in metrology to support safeguards and to an exchange on publicly accessible training infrastructure, training courses and training materials.

DG ENER/E Metrology Training Needs

Petra Klumpp from DG-ENER-E expressed the need of the Euratom safeguards directorate for support in metrology and estimation of uncertainty. This is of major importance in order to be compliant with the latest international standards and for the implementation of the integrated management system (ISM) at DGENER-E. The DGENER IMS team consists of four specialists who are currently, among other tasks, focusing on a 'gap analysis' for ICS and ISO/IEC 9001, 17020, 17021 and 17025 [11, 12, 13, 14]. DGENER provides a large range of lectures, instrument and in-field courses available for newly recruited and experienced inspectors. These training events are very efficient and successful, but DGENER would very much appreciate cooperation with the metrological community in the development of 4 training modules tailor-made for safeguards needs as listed below:

- Applied Metrology in Safeguards – the Concepts
- Quantitative measurement – uncertainty estimation
- Verifying the operators Measurement Control Programme
- Material Balance Evaluation in bulk-handling facilities

The same accounts for guidance and expert advice for:

- Implementation of ISO/IEC 17025
- Uncertainty estimation for NDA measurements
- Standardised MCP checks per facility type
- Standard concepts for MBP evaluation – MUF evaluation & σMUF estimation

Training coordinated by IRMM

Yetunde Aregbe from the EC-JRC-IRMM gave an overview of training and knowledge transfer activities organised or coordinated by IRMM. Since 2001 JRC-IRMM has coordinated TrainMiC®, which is a European programme for life-long learning about how to interpret the metrological requirements of ISO/IEC-17025 for chemical and bio-analytical measurements in many different sectors [46]. It operates across many parts of Europe via national teams. These teams use shareware pedagogic tools which have been harmonized at European level and translated into fourteen different languages. The JRC-IRMM is responsible for the editorial process training material (theory and practical examples) and the training-of-trainers. The training modules as listed below are given by a pool of authorised trainers

- Introduction to metrology in chemistry
- Traceability of measurement results
- Single laboratory validation of measurement procedures
- Uncertainty of measurement: Principles and Approaches to evaluation
- Statistics for analytical chemistry
- Selection and use of reference materials
- Interlaboratory comparisons
- Internal quality control
- Sampling as a part of measurement procedure
- TrainMiC Examples

Practical Examples on Traceability, Measurement Uncertainty and Validation in Chemistry have been published in 2 books available in [47].

JRC-IRMM organises, on a yearly basis, a training course on: Use of Reference Materials and the Estimation of Measurement Uncertainty [48]. This course, although not focusing on nuclear measurements, has become over the years very popular for participants from DGENER-E and is seen to be very beneficial. The course encompasses the following topics:

- Uncertainty estimation
  - What are the basic principles?
  - How to estimate uncertainty from validation data?
  - How can I use reference materials to estimate my measurement uncertainty?
- Establishing traceability
  - What do I have to do to make my results traceable?
  - How can I establish traceability with reference materials?
- Reference material selection
  - Where can I find reference materials?
  - Which material is the right one for me?
- Reference material handling
  - How much of each material must I use?
  - How should I store my materials?
  - How do I correct for moisture?
- Reference materials use
  - How can I demonstrate trueness?
  - How can I demonstrate my method proficiency?
- Making full use of available information
  - What do the terms on a certificate mean?
  - What can I do with a certification report?
- Intensive practice in small groups
  - This course strongly emphasises practical application of theoretical concepts. To this end, each lecture is accompanied by exercises in small groups (5-6 people) during which the concepts are put into practice.

Recently, JRC-IRMM developed training modules on 'improving chemical and ionising radiation metrology' as part of the three-year Europe & Metrology in Turkey (EMIT) project - funded by the European Union under the instrument for pre-accession assistance [49].

- Statistics I Probability distributions
- Statistics II Calculation of a mean
- Accepted approaches to the estimation of uncertainty
- Estimation of uncertainty in radiochemical analysis (Alpha-particle spectrometry)
- Uncertainty estimation in Liquid Scintillation Counting
- Uncertainties in gamma-ray spectrometry

In addition, a number of workshops organised by JRC-IRMM in cooperation with other metrology institutes and experts in the field of metrology in chemistry and ionising radiation, dosimetry, quality control and use of reference materials, auditing etc. were held in the frame of EMIT open to multi-stakeholders. The complete list can be consulted on [50].

The NDA Safeguards Training Laboratory at ITU

Ludwig Holzleitner from the EC-JRC-ITU gave a presentation on the JRC EUSECTRA – European Nuclear Security Training Centre that had just been inaugurated at ITU-Karlsruhe. The training activities carried out are directed mainly to DG ENER and IAEA inspectors and equipment development in the area of non-destructive analysis, chemical and isotopic analysis, mass-volume determinations, containment and surveillance and innovative safeguards approaches. The second component of the training focuses on combating illicit trafficking, including detection, response, and nuclear forensic analysis as recommended by the EU CBRN Action plan adopted by the European Council in

December 2009. The Centre will serve as a platform for knowledge transfer and for networking of experts [51].

The NDA safeguards training facility will provide courses on:

- Uranium enrichment determination by Gamma spectroscopy
- Determination of Plutonium isotopic composition by Gamma spectroscopy
- Passive neutron coincidence counting and determination of fissile mass (Pu240eff)
- Active Neutron coincidence counting (AWCC)
- Advanced RADAR/CRISP (Remote acquisition of data and review)

Other courses are still under discussion and input from DGENER and IAEA is required on prioritising the needs.

- Physical inventory verification (PIV) (license limitations)?
- NDA refresher (to be discussed)?
- Calorimetric measurements (need)?
- MUF evaluation / Statistical analysis: ?
- Stability / Uncertainty / Long term need?
- Resources?
- Support from main customer (DG-ENER)?

An important aspect of the NDA training centre is the avaliability of uranium and plutonium reference materials and ^{244}Cm. Furthermore, the set-up of the JRC EN3S - European Nuclear security and safety school (safeguards, security, forensics, basic nuclear science, etc) for training and education in the nuclear field was menitoned as support to higher academic education.

In this session it was obvious that a number of courses, lectures and training modules are available and under development from both the safeguards and metrology community but that the communication channels between these communities still need to be properly established.

3.8. Working Group

After the five sessions with presentations, the final part of the workshop was dedicated to discussing the findings from those presentations within a working group and to draft a set of recommendations on DA and NDA priorities for reference materials, compliance with international standards, uncertainty and traceability, development of instruments and on modelling. As it was proven to be very efficient and already successfully applied in previous WGDA workshops, the three ESARDA WGs returned to the 'World-Café' approach' [4]. The 'World-Café' is a workshop method based on the assumption of a collective knowledge. The participants are guided to interact in a constructive way in their discussions, where each participant can express his/her point of view. They are spread within different topics, where they deal with a specific question. To each of the topics a facilitator is assigned. After a set time, the participants change within the topics, get a résumé by the facilitator of the topic and restart the discussion with the next question related to this topic. The 'World-Café' was chaired by T Prohaska from BOKU-WIEN with assistance from Y Aregbe and Rožle Jakopič from IRMM, Oscar Alique and Raffaele Bencardino from DGENER-E, and Paolo Peerani from ITU-Ispra. The participants were divided into five groups, of about eight participants per group, to discuss the five topics that had been identified by the participants after all the previous presentations and session discussions. Around these five topics, questions were raised in four rounds and discussed by the working groups in a rotational sequence:

TOPIC A: Reference Materials
- What kind of reference materials are available/needed in DA and NDA?
- What is the appropriate use/need of RM
- What RMs are needed for operators?
- What RMs are needed for novel technologies?
- Can we use RM for calibration of models?

TOPIC B: International standards and field work
- What do we need to be compliant with (international) standards?
- What are the needs for inspectors in the field?
- What is 'fit for purpose'?

TOPIC C: uncertainty and traceability
- What approaches are established for uncertainty calculation? How are they applied?
- What approaches are needed to establish uncertainty?
- How are these calculated/obtained?
- What is 'fit for purpose', where do we need improvements?
- How can we obtain GUM type uncertainties from fits (e.g. in spectra)?
- How can we make use of Monte Carlo in uncertainty calculations?

TOPIC D: Development of Instruments and parameters
- What instrument developments are required?
- What parameters need more research? (e.g. nuclear data, decay constant)?
- Can we define parameters on an international basis, so that only one dataset for a parameter is used?

TOPIC E: Modelling
- How can modelling replace calibration using RMs and where are the limits?
- Does this make sense for nuclear inspectors? Does this work (model validation)?
- Is real-time simulation SciFi?

This approach enabled a first set of recommendations per topic to be drafted and presented to all participants at the end of the workshop day. Those draft recommendations were immediately after the workshop circulated for comments to all participants and subsequently finalised. The following paragraphs list the complete set of recommendations, on the topics identified by the workshop participants.

3.8.1. Recommendations for Reference Materials

The first topic dealt with the difficult task of establishing a priority ranking for reference materials in DA and NDA. As was seen from the presentations given during the sessions, there are a lot of nuclear CRMs available but the list of future needs and developments seems to be even longer. There is, of course, the commitment from reference material producers to provide and develop new materials in response to safeguards authorities and industry needs, but the demands have to be reasonable and to match with available resources, including base materials, both in time of austerity getting scarcer. A limitation in NDA is the commercial availability of standards: also, certified test samples for interlaboratory comparison exercises would be needed. In addition, when no CRMs are available, Monte Carlo and approaches such as 'real time simulation' should be considered as alternative calibration routes (see also paragraph 3.8.5). For novel technologies, reference materials of noble gases are lacking. A re-occurring consideration is to use the reference materials correctly and to think carefully when precious CRMs are really required and when regular RMs or alternative approaches could be used. The recommendations below include a priority list for CRMs in respect of the field of application

Recommendations Topic A- Reference Materials

- RM priority list
  - Replacement of LSD relevant CRMs (U, Pu metals)
  - Spike CRMs of high purity (e.g. ^{233}U, ^{244}Pu, ^{242}Pu)
  - Particle CRMs (U, Pu certified for amount content, isotopic and chemical composition)
  - Uranium CRMs certified for trace elements (impurities, REEs)
  - Age dating CRMs (U, Pu certified for last separation date)
  - CRMs for geo-location
  - Isotopic RMs for mass spectrometer calibration (e.g. Th, Am)
  - NDA-specific reference materials for neutron and gamma techniques need to be addressed (^{240}Pu, ^{244}Cm, ^{252}Cf, Pu, MOX, low and high enriched uranium, specific geometries, etc)
- Bring communities together (to identify the needs)
- Raise awareness on the proper use of RMs (CRM *vs*. RM)
- RMs for novel technologies (reference samples for study of conversion electron transition yields, Xe, ^{85}Kr, ^{37} Ar)
- Website for open discussion; international library (storage) of RM
- Proficiency testing for other (than mass spectrometry) techniques

It is obvious looking at the recommendation list that the current workshop can only address the 'Tip of the Iceberg' on this topic. The workshop participants recommended continuing the series of IAEA technical meetings on nuclear reference materials for safeguards verification measurements by destructive analysis (last held in 2009), and including relevant topics on screening measurements applying NDA techniques in the next IAEA technical meeting on bulk analysis of environmental swipes samples.

3.8.2. Recommendations for International standards and field work

The second topic dealt with needs in nuclear safeguards regarding standards for measurement uncertainty calculation and its use in nuclear safeguards. The recommendations were directed at using the available standards and agreed framework already used in metrology to the maximum possible extent, in order to put an end to the historic isolation of nuclear safeguards from other disciplines.

Recommendations Topic B- International standards and field work

- Need for validated methods
- Use of latest international standards for conformity assessment
- Try to find a solution to the terminology problem (working group?)
- Encourage publications of detailed procedures and results
- Clarify and ensure the compatibility of GUM and σMUF estimation methods in procedures and documents
- Guide for ‘smart’ sampling
- Sensitisation for and promotion of best practice in safeguards MCP
- Enhance exchange of knowledge

- need to find a solution to the isolation of the Nuclear Safeguards community
- draft a curriculum for metrology training tailored to safeguards actors

As can be seen from the recommendation list, the use of available models and terminology issued by recognised international organisations and finding a way to make them compatible with current safeguards practices is a priority, in order to make use of reliable measurement results and uncertainties for nuclear safeguards purposes.

3.8.3. Recommendations for uncertainty and traceability

The third topic dealt with approaches to establish, for measurement results in DA or NDA, a transparent uncertainty budget, preferably traceability to the SI. The different points of view on uncertainties from the operators' side, facing high sample throughput while delivering economic output, compared to the evaluators, who are using models to evaluate data and have to draw safeguards conclusions, were discussed. There was agreement that available guidelines, such as the GUM and the VIM, should be promoted and are indispensable to investigate 'the gap' in uncertainty approaches between evaluators and the measurement community. A limiting factor is the complexity of software tools to calculate uncertainties. In that respect the initiative of CEA and AREVA to issue a guide, together with the respective excel sheet for calculation of uncertainties, was seen as an excellent example of harmonisation between operator and nuclear laboratories. Particularly in NDA measurements, efforts in exchanging with code developers have to be continued towards more transparency on built-in uncertainty estimation for codes, including the uncertainties of nuclear data. The workshop participants were also very positive in using Monte Carlo for calculating uncertainties and develop models.

Recommendations Topic C- uncertainty and traceability

- Needs for separate workshops/meetings
  - Uncertainty of sampling
  - Follow up meeting of experts (metrologists AND evaluators) to investigate on the ‘gap’ between their respective approaches
  - Workshop to increase the understanding of the scientific community on the needs of inspectors/evaluators
- Use/provide simple tools to calculate uncertainties
- Make use of Monte Carlo for calculating uncertainties and develop models (use MC knowing the model)
- Create a simulated dataset for testing analysis software (for result and the respective uncertainty)
- Create a simulated dataset for testing analysis software (for result and the respective uncertainty)
- Encourage publications on detailed uncertainty approaches in DA and NDA
- More transparency on built-in uncertainty estimation for codes (e.g. isotopic composition) used in NDA (IWG on γ-spectrometry techniques [3])
  - establish communication between code developers and users (get away from the black box approach)
- Training on improving the common understanding towards harmonized (measurement/uncertainty/traceability) approaches, drafting a syllabus for metrology training in safeguards
- Information sessions for operators on uncertainty estimation (cost/effort *vs*. benefit) (awareness – training – exercise); create awareness that without proper uncertainties no decision can be made

- Integrate measurement aspects in SSAC (IAEA) training courses; metrology training via EC-SP or other platforms
- Awareness of hierarchy on the benefits to ' invest' in proper knowledge and application of uncertainty and traceability concepts
- Increase synergy (IAEA-DGENER) on training issues (high level/low level liaison committees)
- Increase exchange between safeguards and metrology communities

As can be seen from the recommendation list, one crucial point for improvement identified by the workshop participants and suggested for follow-up is that proper communication channels need to be established between DGENER, IAEA and training providers on metrological concepts. On the one hand, safeguards staff should participate more in training courses on metrological concepts organised outside the safeguards community. At the same time, integration of metrology experts in IAEA and DGENER technical meetings and training courses is required. In addition, mutual participation of DGENER and IAEA staff in training courses, e.g. on Material Balance Evaluation, is strongly recommended. Particularly in view of the current generation-change within the hierarchy of both the nuclear industry and inspection authorities, effective knowledge transfer is essential. Training of operators and code developers in relevant uncertainty estimation is seen as highly beneficial.

3.8.4. Recommendations for development of Instruments and parameters

The fourth topic dealt with was Development of Instruments and Investigation of Parameters. The working groups agreed on the following set of recommendations, after discussing the state of the art, the current needs, and the actual limitations.

Recommendations Topic D- Development of instruments and parameter

- Increase knowledge and communication;

  According to the philosophy of this multidisciplinary workshop, a greater effort should be made to prioritise the research, measurement and safeguard activities, building on a better knowledge of the links between actions and needs. As a possible scenario, the priority assigned to the development of a measurement technique should be higher when related to a specific safeguards need.

- Validation of NDA methods in the field;

  Stable measurement techniques in a laboratory environment often cannot be reliably implemented in field. A trend towards adapting the instruments to perform in a harsh industrial environment was considered very valuable to safeguards.

- Suitable CRMs and computer models for method/instrument validation in DA and NDA;

  Development and availability of reference materials was considered crucial in the particular cases of Calorimetry, environmental sampling and novel technologies. As described in the next section, modelling is expected to trade off with the increase of need for reference materials.

- Working on the level of confidence in uncertainty estimations;

  Nuclear safeguards organisations, reference measurement and metrology institutes, nuclear measurement laboratories, nuclear industry and environmental sciences institutes are encouraged to work towards a uniform understanding of uncertainty estimation. As outlined in topic C, a closer cooperation between the stakeholders is needed to provide estimations which are reasonable, reliable, traceable, and suitable for cross correlations of measurements performed in independent environments.

- Harmonize databases on nuclear data for the use of libraries;

  For historical and logistical reasons, independent data-bases have been developed and maintained. They provide nuclear data, details on the source experiments or models, and tools for benchmarking datasets. When discrepancies arise, the nuclear libraries do not provide an independent assessment of the reliability of the data sets. Such an assessment was considered to be very beneficial to the end user, as well as the definition of parameters on an international basis, so that eventually only one dataset would be used.

- Deeper understanding on phenomena and technical details;

  The basic physics of uncertainties, models and instrument development needs to be addressed via training targeted at the safeguards needs. It is recommended to extend the technical knowledge required at the inspectors' recruitment level, as currently done by the safeguards support teams.

- Oversight and awareness;

  Scan the horizon to be aware of latest technologies, trends, ideas, solutions to pending problems approached by different disciplines.

- More optimism towards novel technologies;

  Free from inherited limitations and bias, the field of Novel Technologies was recognised to be particularly promising to support the evolving safeguards strategies. The community is encouraged to sustain the enthusiasm for innovation, and to tailor the work to the context and the specific demand - especially during austerity-driven political scenarios.

As can be seen from the recommendation list, an element of great relevance to improve the synergy between the parties is awareness. Being aware of what is available; what is needed; how other fields would approach similar problems; understand what the real needs are; and what the links between action and need are, are considered to be the key aspects to develop further instruments and parameters.

3.8.5. Recommendations for Modelling

The fifth topic dealt with the possible benefit of the reduction in need of RM and better estimation of uncertainties that could derive from modelling.

When analysing the state of the art, it has been commonly realised that existing tools have reached a satisfactory level of maturity. Computational calibration can indeed reduce, if not replace, the need for RM in NDA techniques [52].

Concerning the needs identified during the workshop, we can include the extension of NDA to new emerging applications (such as advanced fuel cycles, high-burnup) and spent fuel); the necessity to develop user friendly interfaces in order to simplify the skill required by the user (the inspector should not need to be a modelling specialist); tools for automatic import of data for modelling (such as operator declarations, detector properties,etc): and enhanced portable computing capabilities. It has also been envisaged to establish a reach-back procedure: expertise on modelling available at inspectorate headquarters ready to provide support to the in-field inspector.

The major limitations were assumed to derive from the difficulty to gather all the necessary “ground truth” data, the implementation of in-field modelling tools, the limited computational capability and the difficulty in accurate modelling of real cases that could reach a high level of complexity.

Based on all the above considerations, the workshop participants drafted the following recommendations:

Recommendations Topic E- Modelling

- Develop knowledge in inspectorates (mostly through training)
- Improve the interaction between model & instrument developers and users
- Reinforce validation (need for RM)
- Improved nuclear data: develop priority list
- Exploit pre-info capability at headquarters (e.g. possibility of pre-calculated scenario + interpretation)
- Investigate computation capabilities for resident/portable applications
- Improvement in the codes (some physical processes are not yet mastered and some particles (e.g. muons; antineutrinos) are not treated
- Tools for translation of real geometry into digital

As can be seen from the recommendation list, collaboration between different stakeholders should be enhanced. In particular, an interaction between modellers and inspectors (mostly through training, but not exclusively) could improve awareness of the potential of modelling and its benefit for inspector work, fostering the level of acceptance and exploitation.

4. Summary and Outlook

ESARDA is a platform for exchange on R&D between safeguards, industry and measurement communities. This interdisciplinary workshop of three ESARDA WGs was organised as a pilot event to follow-up recommendations from previous workshops. With discipline, dedication and enthusiasm, the participants met the challenge given by the broad objectives without losing the focus on the essential topics. Excellent technical presentations were given in the sessions and lively discussions held in the working group.
This dedicated workshop succeeded in bringing closer together experts from communities that usually do not exchange on a regular basis, increasing the understanding based on metrological principles and the GUM between different approaches in uncertainty estimation for DA, NDA and the essential role of reference materials. For the first time in a dedicated workshop, a full session was dedicated to safeguards inspection and evaluation. This was recognised by the participants from the research community and metrology institutes as an asset of the workshop, to learn more about the way safeguards data are processed and how safeguards decisions are derived from data sets.

The discussions held in the working groups and the sessions resulted in broad recommendations, which cannot all be followed up by the ESARDA WGs, but there was an overall agreement to use this momentum to go a step further and follow-up using various platforms on topics (just to mention a few) such as:

- Compatibility between GUM and uncertainty models for material balance evaluation
- Harmonisation of terminology (VIM)
- Implementation of respective ISO standards
- Training on metrological concepts for inspectors in the field – syllabus for metrology training in safeguards
- Increase in synergies IAEA-DGENER on training issues (high level/low level liaison committees)
- Harmonisation of approaches in uncertainty estimation between industry, laboratories and safeguards authorities
- Development and prioritisation of new CRMs in DA and NDA

- Reviving the IAEA technical meetings on nuclear reference materials for safeguards verification measurements by destructive analysis
- Modelling as an alternative to calibration with RMs in NDA
- Improvement in the interaction between model & instrument developers and users, also towards novel approaches
- Validation of user-friendly software for fitting by means of simple data sets and then by RMs
- Harmonisation of databases for nuclear data
- Promote management awareness of the benefit of education/training of their staff in proper uncertainty estimation

The outcome of this pilot workshop confirmed the usefulness and the need for regular joint activities of the three WGs, involving experts from different fields. With the present detailed report, the three WGs would like to share the outcome and technical topics discussed with a broad community.

Important web links:

A) Guides:

- ITV2010:http://esarda2.jrc.it/internal_activities/WG-DA/STR_368_--_International_Target_Values_2010_for_Measurement_Uncertainties_in_Safeguarding_Nuclear_Materials.pdf
- International vocabulary of metrology – Basic and general concepts and associated terms (VIM): http://www.bipm.org/en/publications/guides/vim.html
- The new EURATOM/CITAC guide: http://eurachem.org/index.php/publications/guides/quam
- Guide to the expression of uncertainty in measurement - GUM: http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf
- Evaluation of measurement data — Guide to the expression of uncertainty in measurement Evaluation of measurement data — Supplement 1 to the "Guide to the expression of uncertainty in measurement" — Propagation of distributions using a Monte Carlo method http://www.bipm.org/en/publications/guides/gum.html

B) Training courses:

- TRAINMIC: http://irmm.jrc.ec.europa.eu/TRAINING/TRAINMIC/Pages/index.aspx
- Europe and Metrology in Turkey (EMIT) - Improving chemical and ionising radiation metrology in Turkey: http://irmm.jrc.ec.europa.eu/Turkey
- Use of reference materials and the estimation of measurement uncertainty: http://irmm.jrc.ec.europa.eu/events/Documents/2013-10-09_SURM%20leaflet.pdf
- http://irmm.jrc.ec.europa.eu/training/Pages/index.aspx

C) Conferences/Workshops:

- International Conference on Radionuclide Metrology and its Applications, 17-21 June, 2013, Antwerp; http://irmm.jrc.ec.europa.eu/events/Pages/130617-21_icrm_2013.aspx
- A workshop on Analytical Development and Reference Materials in the Nuclear Fuel Cycle, Avignon, June 20-21, 2013: http://www.astm.org/filtrexx40.cgi?+-P+MAINCOMM+C26+-P+EVENT_ID+2382+-P+MEETING_ID+81672+/usr6/htdocs/newpilot.com/MEETINGS/sympotherinfo.frm
- GAMMA-2 Workshop, Novi Sad, Republic of Serbia, 24-26 September 2013; http://irmm.jrc.ec.europa.eu/events/Pages/130924-26-Gamma-2.aspx
- ESARDA symposium 2013; http://esarda.jrc.ec.europa.eu/index.php?option=com_content&view=article&id=70&Itemid=238
- Congrès International de Métrologie, 7-10 October in Paris: http://www.metrologie2013.com/

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5. List of Acronyms

- **CRM** – Certified Reference Material
- **COMPUCEA** - Combined Procedure for Uranium Concentration and Enrichment Assay
- **DU** – Depleted uranium
- **(FT)-TIMS** – (Fission-Track) -Thermal Ionisation Mass Spectrometry
- **GSMS** – Gas Source Mass Spectrometry
- **GUM** - Guide to the expression of uncertainty in measurement
- **HEU –** High-enriched uranium
- **ICP-(SF)MS** - Inductively Coupled Plasma - (Sector Field) Mass Spectrometry
- **IDMS** – Isotope Dilution Mass Spectrometry
- **ILC** – Interlaboratory Comparison
- **LA-MC-ICP-MS** - Laser Ablation Multi Collector Inductively Coupled Plasma Mass Spectrometry
- **LEU –** Low-enriched Uranium
- **(LG)-SIMS** – (Large Geometry) Secondary Ion Mass Spectrometry
- **MBA** – Material Balance Evaluation
- **MCP** – Measurement Control Program
- **MUF** – Material Unaccounted For
- **σMUF** – Material Unaccounted For uncertainty
- **NMAC** – Nuclear Material Accountancy
- **NWA**L - Network of Analytical Laboratories
- **RM** - Reference Material
- **SRD** – Shipper Receiver Difference
- **UOC** – Uranium Ore Concentrate
- **WG NA/NT** - Working Group on Novel Approaches and Novel Technologies
- **WG DA** - Working Group on Standards and Techniques for Destructive Analysis
- **WG NDA** - Working Group on Standards and Techniques for Non-Destructive Analysis
- **WS** – Workshop
- **VIM -** International vocabulary of basic and general terms in Metrology
- **ITV** - International Target Values for Measurement Uncertainties in Safeguarding Nuclear Materials

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