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Nuclear Safeguards R&D and Innovation at the JRC

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Abstract. Nuclear safeguards are from the very origin of the Joint Research Centre (JRC), and as enshrined in the EURATOM Treaty, a key duty of the European Commission and a field in which JRC has a fully unique position in Europe. In this area JRC is an un-replaceable R&D partner of Euratom safeguards authority and IAEA through its very extensive support programme. The JRC R&D safeguards programme aims in one hand at maintaining traditional safeguards at level so that deterrence to diversion from civil cycle remains high, taking into account that more installations will need to be safeguarded by EU and international authorities. This relies on development of advanced NDA, DA and CS techniques, full remote and unattended (authenticated) technology and stringent quality systems in measurements and results delivery. In another hand the RD programme put more focus on material flows in sensitive uranium and spent fuel handling facilities and use of fingerprinting techniques to cover diversion scenarios and more performing and accurate environmental sampling techniques and traces analysis. Open-source analysis and development of new tools and methodologies for the control of Import/export are areas where the effort is also increased. In the JRC R&D programme a special attention is also given to the development of accountancy and safeguards concepts for advanced fuel cycles (GenIV) as well as proliferation resistance methodology. This scientific/technical work is encompassed by appropriate training activities. This paper is about some of the new R&D and innovation activities of the JRC as part of the EU contribution to the implementation of effective nuclear safeguards inside and outside the EU.

1. Introduction

Nuclear Safeguards, as any other treaty monitoring activity, depends highly on technological development. Indeed, there must be a constant evolution and improvement of the tools and methods used to be able to "stay ahead of the game".

There is a close link between technology and the implementation of Safeguards. Indeed, the state of the art in technology can determine the approach to safeguarding an installation. Vice-versa, the perception of gaps, be the experienced or merely theoretical, can provide guidelines for further research and technological development.

From a technical point of view, Nuclear Safeguards is mostly an area of integration, combining at a single moment, the best tools and techniques available. The evaluation of new techniques is mainly based on criteria of effectiveness, efficiency, and cost.

Efforts to improve Nuclear Safeguards can go along different lines, including:

a) Better instruments, leading to better measurements with improved accuracy and less dispersion.
b) Better process models – including new signal processing techniques
c) Data Fusion – combining data from multiple sensors, measurements and time frames
d) New technologies
e) Integration and presentation of information – leading to better responsiveness, timeliness and more intuitive situation awareness

The JRC nuclear activities are carried out within the Framework Programme (FP) of the European Atomic

Energy Community for nuclear research and training activities. The current programme is the seventh (FP7) covering the period 2007-2011-2013 [1]. An important activity of the programme aims at contribution to the development of efficient and effective systems for the safeguards and proliferation resistance of current and future nuclear fuel cycle systems [2]. This implies tackling R&D challenges in the areas of nuclear materials measurements, containment and surveillance, information technology and process monitoring and modelling. These activities are performed in close collaboration with Euratom and IAEA safeguard inspectorates as main end users.

Three JRC institutes contribute to the implementation of the nuclear safeguard part of the JRC Euratom program and thus actively collaborate with the IAEA within the framework of EC-SP. These are:

- Institute for the Protection and Security of the Citizen (IPSC), Ispra, Italy
- Institute for Reference Measurements and Materials (IRMM), Geel, Belgium
- Institute for Transuranium Elements (ITU), Karlsruhe, Germany

The following sections detail some current and new research lines performed at JRC institutes, which may be of impact for future Safeguards related technologies and methods.

2. Information Analysis for Non-Proliferation Studies

The European Media Monitor (EMM) is a web-based application developed by JRC-IPSC which automatically collects and analyzes news articles from a pre-defined list of Open Sources (http://emm.newsbrief.eu/overview.html). It currently monitors more than 2,500 news sites – with multi lingual, world wide coverage– in near-real-time and collects more than 100,000 new items each day. EMM automatically analyzes the full-text articles and groups them into thematic and geographic categories. EMM offers additional analysis tools to fight information overflow including e.g. detection of breaking news, entity extraction, duplicate detection and trend analysis.

2.1 Nuclear Security Media Monitor (NSMM)

Since the scope of the EMM Newsbrief is broad, it monitors mainly general news sites. Only few sites of specific nuclear interest are included and the category definitions are of general interest, making it difficult to locate nuclear specific news.

Therefore, JRC-IPSC is currently considering the development of a Nuclear Security Media Monitor (NSMM): a domain specific version of EMM focusing on Nuclear Security issues. It uses the same underlying engine for collecting and analysing news articles, but it will be configured to better serve the needs of the Nuclear Security community.

Over one hundred nuclear-specific sources have been already identified to be monitored by NSMM. In addition to nuclear-related news media, they also include governmental sites, NGOs, nuclear blogs or sites providing relevant scientific or technical information. By defining domain-specific categories, NSMM will allow monitoring specific issues relevant to the Nuclear Security community, such as e.g. illicit trafficking, export control violations, treaty violations or nuclear trade related events.

A NSMM can provide a unique resource for early warning and information awareness customized to the needs of the Nuclear Security community. Applications are been investigated for the areas of (a) Nuclear Fuel Cycle - different phases, (b) Illicit trafficking of nuclear material and (c) Dual-use equipment. Once completed and in operation a NSMM will contribute to the need of more information driven safeguards verification activities.

3. Development of New Reference Materials

3.1 Age Dating Reference Particles

Isotopic reference materials certified for the age of nuclear material (uranium, plutonium) are needed in the fields of nuclear forensics and environmental measurements; therefore a feasibility study for the development of plutonium reference materials for age dating has recently been started at JRC-IRMM in co-operation with JRC-ITU. For the age estimation of a real sample, such as material seized in nuclear forensics investigations or a dust sample in environmental measurements, it is advisable to use more than one clock in order to ensure the reliability of the results and to exclude the possibility that the sample under question is a mixture of two or more materials. Consequently, a future reference material certified for separation date should ideally be certified for more than one "clock" or several reference materials for different "clocks" should be developed. [3]

3.2 Uranium Oxyfluoride Reference Particles

Recently improvements in the production and characterisation of uranium reference particles from certified UF6 reference materials mimicking the “real-life” process of uraniumoxyfluoride particles as observed in enrichment facilities and collected on swipes by safeguards inspectors. These certified test samples are used in interlaboratory comparisons (NUSIMEP) and as quality control samples. The improvement in particle production enables for the first time the preparation of planchets loaded with particles of different 235U enrichment. Also new approaches in micro-Raman spectrometry (MRS) to investigate the molecular form has been successfully applied giving possible indication on the source of origin .of uranium-bearing particles collected on swipes [4].

3.3 Reference Particles Certified for Isotopic Abundances And Uranium Amount Content

It is a significant drawback for the Network of Analytical laboratories – NWAL, that mono-dispersed uranium reference particles, certified for isotopic abundances and uranium amount content per particle, are not available. These reference particles are needed to optimise the overall transmission efficiency in Secondary Ion Mass Spectrometer (SIMS) analysis. JRC-IRMM in cooperation with JRC-ITU took up the challenge to investigate new approaches in the development of a uranium particle reference material certified at the 2.6pg U per single particle. This requires thinking out of the box for isotope dilution mass spectrometry to achieve this goal. It is important since new large geometry SIMS instruments will be installed at JRC-ITU and at the IAEA-SGAS providing high quality and reliability with fast analysis increasing timeliness when safeguarding an enrichment facility. Particularly to enable the precise analysis of the 236U/238U ratio in particles from swipe samples, since 236U is an important environmental and nuclear trace but often with abundance close to the detection limit. Precise 236U analysis is presently not possible with current SIMS techniques.

4. Large Geometry Secondary Ion Mass Spectroscopy – LG-SIMS

JRC-ITU is currently in the process of acquiring a Large Geometry Secondary Ion Mass Spectroscopy instrument – LG-SIMS. This instrument is the very same as the one that the IAEA will have in a near future as part of the new SAL laboratories.

The performance of LG-SIMS has been demonstrated to have a significantly better overall performance in uranium particle analysis compared to current Small Geometry SG-SIMS, due to the removal of background interferences without loss in the useful yield. Use of a multi ion counting system that currently is available for LG -SIMS can improve the counting statistics in the measurements approximately 5-fold. This reduces the uncertainties in the measurements and is an additional advantage for the LG-SIMS as the amount of material in uranium particles from swipe samples often are on the very borderline of what can be analysed. Thus, it should be possible to analyse smaller sized particles in the samples with LG-SIMS than is currently possible.

It is concluded [5] that the use of an LG-SIMS offers particular advantages in the speed and thoroughness of analysis for this particular application. First, a larger number of particles can be deposited per planchet as it is no longer critical to avoid the sputtering of material surrounding the uranium particles, which is a necessity in SG-SIMS measurements. Normal sample loadings for routine analysis with conventional SG-SIMS are a few million particles per planchet whereas the LG-SIMS is able to handle at least an order of magnitude more material. This significantly improves the ability to detect a uranium particle in a matrix of other material. Another consequence of the background removal is that it simplifies the search for uranium particles, as it is easier to spot the particles of interest thus improving timeliness. The multi ion counting system can also be operated for multi isotope imaging offering the possibility to make faster screening measurements with new dedicated particle search software that is under development.

The LG-SIMS offers advantages with regard to the FT-TIMS analysis process as well. Sample preparation can take mere minutes and does not require a reactor offering quick sample turn-a-round and same-day analysis. Taking advantage of the imaging capabilities, high resolution and high useful yield (1.2%), the

LG-SIMS can quickly locate particles in a matrix, and can both provide high precision isotopic measurements and survey the isotopic distribution of thousands of particles within a sample.

The main limitation in LG-SIMS measurements compared to TIMS is in the 236U measurements due to the necessity for a hydrogen correction. It has also been demonstrated that while mass bias and fractionation effects must be compensated for, they are a small component of the total uncertainty compared to the effect of the counting statistics on pg to sub-pg amounts of material available in real sample particles.

5. Developments in Mass Spectrometry Techniques

The so-called "modified total evaporation technique" in thermal ionization mass spectrometry (TIMS) has been developed in collaboration with "key nuclear safeguards laboratories" (NBL, IAEA/SGAS, ITU) with IRMM taking the initiative and the leading role. This method improved the capabilities and sample throughput in particular for measurements of the minor uranium isotope ratios. It has just recently been implemented at ITU and IAEA/SGAS. It allows the determination of the $^{235}U/^{238}U$ major ratio as well as of the $^{234}U/^{238}U$ and $^{236}U/^{238}U$ minor ratios, within the same measurement, with improved precision and accuracy, and on a routine basis. The performance of the MTE method for the minor uranium ratios $n(^{234}U)/n(^{238}U)$ and $n(^{236}U)/n(^{238}U)$ is shown in Fig. 1. It is well below the performance limit for the entire range of ratios as required by the IAEA . The excellent performance of this technique was demonstrated and will be officially accepted for safeguards measurements at the IAEA SGAS since the minor uranium ratios are measured in almost all of the environmental samples at the IAEA-SGAS and the IAEA Network of Analytical Laboratories.

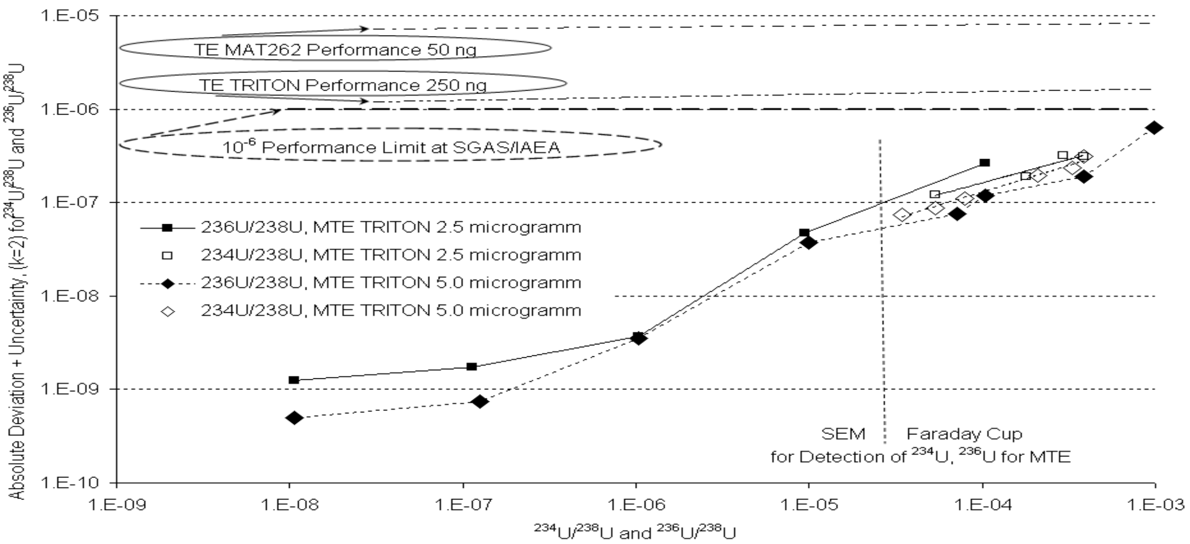

Fig. 1performance of the MTE method for the minor uranium ratios $n(^{234}U)/n(^{238}U)$ and $n(^{236}U)/n(^{238}U)$

This method is also particularly suitable to "access" information that is inherent in uranium minor isotopes results from the viewpoint of nuclear forensics. Minor isotope measurements in uranium samples help in source attribution and are an important part of 'nuclear fingerprinting' of discovered, unknown material. Furthermore, relations between materials can be established by means of minor isotope measurements in uranium samples.

6. Development of Safeguards Concepts for Advanced Nuclear Cycles

JRC-ITU is pursuing a substantial research programme devoted to the partitioning and transmutation (P&T) of spent fuels. This includes both investigations on advanced processes for improved actinide and fission product separation, and the development of special fuels for transmutation. Among the different approaches for partitioning, major efforts are being directed towards the development and testing of pyrochemical reprocessing techniques. For this purpose dedicated test facilities for studying pyro-reprocessing with non-irradiated test fuels as well as with real fuels have been set up at JRC-ITU.

This work will also focus on the development of safeguards concepts for advanced fuel cycles. Apart from process development, the test facilities will serve the purpose of building measurement schemes to fulfil safeguards objectives.

The ongoing research work on the pyro-reprocessing technology requires continuous analytical support for (timely) analysis of the various process samples in order to verify and to assess the quality and efficiency of the respective separation processes. Over the years some of this analytical support, especially for minor actinide analysis, has been also provided by various radiometric techniques as far as they appeared applicable. The radiometric techniques used for this purpose at JRC-ITU included mainly X-ray fluorescence analysis (XRF), high-resolution gamma spectrometry (HRGS), passive neutron coincidence counting (PNCC), and occasionally also calorimetry. The measurements were made with instrumentations coupled to gloveboxes, which allow the handling of non-irradiated nuclear materials. The analytical support with the radiometric techniques was therefore possible as long as the investigations for pyro-reprocessing were conducted with these types of materials [6].

Meanwhile the research work at JRC-ITU on the pyro-reprocessing techniques is proceeding to experimental studies, which also include actual irradiated nuclear fuels. In order to be able to provide further analytical support for this new type of highly radioactive process specimens, the measurement environment for the radiometric analysis techniques needed to be adapted accordingly. This has led to the conception and practical realization of a versatile NDA measurement station for the analysis of irradiated fuel samples.

7. Infield Tools for the "Investigative Inspector"

One of the objectives of the IAEA is to "deter the proliferation of nuclear weapons, by detecting early the misuse of nuclear material or technology, and by providing credible assurances that States are honouring their safeguards obligations". In recent years the Safeguards approach has included the verification of state of the completeness of State declarations. To this effect, the Additional Protocol introduced a new family of legal instruments and modalities towards that objective. Unannounced inspections are one of such instruments, which will likely lead to changes in the way Safeguards inspectors operate. Monitoring for undeclared activities includes checking predictable compliance criteria as well as coping with unexpected scenarios. For the latter, the provision of in-field information to support the inspection is of paramount importance – as not all scenarios can be studied at Headquarters while preparing an unannounced inspection. To be useful, the information to be provided to the inspector must relate to the field context and must be comprehensive in content. The R&D activities are rooted mainly in the field of machine intelligence including: virtual reality, human-computer interactions involving augmented reality and information integration for improved situation awareness.

The scope of this activity is to investigate tools, components and system architectures to be used by a Safeguards inspector to enhance her/his observation and "investigative" skills as well as securely retrieves local, just-in-time information while performing a complementary access inspection. The scientific disciplines supporting this project include augmented and mixed reality, ambient intelligence, and environment localisation as well as secure communications.

As an example of the current work, the project will implement and demonstrate a prototype system of a multifunctional handheld device equipped with positioning sensors and a combined real-time 2D/3D data capture to assist an Inspector in performing a complementary access inspection. The Inspector will be able to interact with the device and have additional information, such as description of physical objects and instruction for performing physical tasks in form of annotation, off-the-shelf synthesizer-based speech instruction, image, and 3D model. Such prototype will illustrate the potential of the new tools assisting an inspector. A possible goal includes the incorporation into one handheld piece of equipment diversified data gathering (e.g. radiation, thermal, spatial, chemical, environmental, distance measurements) and analysis capabilities.

8. Real-time Simulation of Neutron Counters

JRC-IPSC has developed methods (based on Monte Carlo techniques) to simulate the behaviour of NDA instruments used in nuclear safeguards. Physical models of most neutron devices have been also generated and validated. The simulation technique has become a valid and valuable tool to replace measurement every time the experiment is impossible (for instance due to lack of reference materials) or simply too cumbersome.

The main complication in the calibration procedure of NDA techniques derives from the extremely high sensitivity of these measurements to a lot of parameters: geometry (shape and dimension), chemical/physical form, container, impurities. An accurate calibration procedure requires a set of standards being as similar as possible to the samples to be measured. Due to the high number of (sometime costly) reference materials required by NDA techniques, it becomes fundamental to investigate and develop methodologies giving the possibility to reduce these requirements. This task can be performed by numerical simulation. This research work aims at a full automated and real-time coupling of numerical simulation to NDA measurements.

There are real cases where it is not possible to build at all a calibration curve, intended as a unique relationship between sample mass and counting rate. This means that a dedicated Monte Carlo run needs to be performed once the measurement configuration of the item is known. In order to help the inspector in this task, JRC is developing user interfaces allowing the inspector to create an input file for the Monte Carlo code for the declared loading fuel configuration. Initially a base input file of the model containing details of the detector geometry and its materials and other necessary information is pre-loaded and the inspector may need only to change the loading positions, the fuel type and isotopic composition.

Nevertheless the long computing times required today to simulate the measurements allow just an “a posteriori” verification of the measurement. An ideal system should work on real time, that means:

- receive the declaration on the sample characteristics together with the sample to be physically measured
- process the information in order to produce automatically an input file for the simulation code
- launch the calculation in parallel with the measurement
- compare the simulation results with the measured data immediately in order to have an instantaneous answer on the correctness of the sample declaration

The way we envisage real-time simulation of neutron counters impacts the usual way of using NDA measurements to verify nuclear material and requires a mentality change of inspector perspective. It is not simply the fact that we introduce a physical modelling as integral part of the experimental process, but also the change in the verification paradigm that compares no longer declared to measured mass, but expected to measured count rates.

9. Combined CAlorimetry-NEutron coincidence counting- GAmma spectrometry (CANEGA)

In the international safeguarding of nuclear materials the prime nondestructive assay (NDA) technique currently employed for plutonium measurements is neutron coincidence counting, combined with gamma spectrometry. One limitation of this kind of plutonium assay arises from the fact that the abundance of the isotope ^{242}Pu cannot be determined by gamma spectrometry because of the absence of a detectable gamma-ray signature from this isotope. This deficiency starts to limit the accuracy of the plutonium assay particularly for higher burn-up materials, where ^{242}Pu contributes 25 % or more to the measured neutron coincidence rate. In this situation recourse is therefore often made to isotope correlations in order to obtain a rough estimate for the ^{242}Pu isotope abundance. The proposed isotope correlations work reasonably well only for defined categories of plutonium materials of known burnup history. However, this information is in practice not readily available for the materials to be assayed, leaving therefore often relatively large uncertainties for the estimated ^{242}Pu abundances. This uncertainty normally affects the performance both of the plutonium isotope abundance measurements and of the quantitative determination of the amount of plutonium. The use of a combined Calorimetry-Neutron Coincidence Counting-Gamma Spectrometry (CANEGA) assay can improve this unsatisfactory situation, The combination of the six directly measurable quantities as obtained from the three measurement techniques, namely the thermal power P from calorimetry, the effective mass m_{240eff} of ^{240}Pu from neutron coincidence counting (NCC), and the plutonium isotope ratios 238/239, 240/239 and 241/239 and ^{241}Am/239 from high-resolution gamma spectrometry (HRGS) allow to determine the ^{242}Pu isotope abundance, which otherwise cannot be directly obtained from a HRGS measurement. In this manner the CANEGA measurement approach provides a more complete fingerprint for any plutonium-bearing sample under assay, which in turn helps to improve the overall accuracy of the plutonium mass determination.

The redundant information from combined CAL/NCC measurements has also proved to be extremely helpful for the plutonium assay in plutonium materials bearing the risk of a potential contamination with ^{244}Cm.. The presence of small amounts of ^{244}Cm in plutonium can quickly invalidate a plutonium assay by NCC as shown in Fig. 7 because of the very high specific emission rate of spontaneous fission neutrons from ^{244}Cm, which exceeds the neutron emission rate from plutonium isotopes by about 4 orders of magnitude. The significantly lower sensitivity of a calorimetric assay to this isotope provides a good means of control for the NCC measurements. Combined CAL/NCC/HRGS measurements will also offer NDA measurement capabilities for a number of special types of nuclear materials, where a single technique would not be able to give an adequate measurement answer.

10. Development of Alternative Techniques for Neutron Detection

Most of the current neutron detection systems used for nuclear safeguards and security are based on the He-3 technology. Unfortunately in the last years the market of He-3 has encountered huge problems in matching the offer and the demand. The need has grown significantly due to the increasing demand of instrumentation for security. This has caused from one side an exponential increase of price (up to a factor 10) and on the other side a serious strategic problem of supply (some manufacturers are not able to assure the production of instruments). The scope of this work is to guarantee the availability of detection systems for nuclear safeguards and security, and hence the development of alternative detection systems based on technologies other than He-3. The main advantages of He-3 detectors are the very high efficiency and the nearly perfect discrimination from gamma signal that makes them ideal for security applications. He-3 is universally considered the “golden standard” for neutron detection. It will be very unlikely, if not totally impossible, to develop neutron detectors having overall characteristics better than He-3.
The main neutron detection technologies that could in principle compete with He-3 are:

- BF_3 gas-filled proportional detectors
- Boron-lined proportional detectors
- Semiconductor neutron detectors
- Scintillation neutron detectors, including:
  - liquid organic scintillators,
  - plastic scintillators,
  - neutron-sensitive scintillating glasses
  - neutron-sensitive scintillating fibres
  - neutron-sensitive fibres coated with scintillating material

Boron fluoride is a poisonous gas and for this reason has not found frequently practical applications. Semiconductor crystals suffer from limitations in size that limit their detection efficiency; therefore they can find some niche application for small equipment.

Boron-lined gas-filled proportional counters are probably the more practical short-term solution. They are already available in the market. Geometrically they are identical to He-3 counters, so they can simply replace the existing tubes without the need of reengineering the entire detection system. The only disadvantage is the relatively low detection efficiency; a boron-lined proportional counter has efficiency approximately 7-times lower than a He-3 counter of the same size. This could be acceptable in security, but is a strong limiting factor in safeguards.

Scintillation neutron detectors could be a longer term alternative to He-3 with respect to boron-lined counters. Scintillation detectors need a totally different (and generally more sophisticated) electronics than proportional counters, but on the other hand the detector itself is generally very cheap. Scintillation detectors have another potential interest. They are also sensitive to gamma radiation. This can be an advantage or a problem. In some cases it opens the possibility to have a single all-in-one gamma/neutron detector under the necessary condition that it is feasible a high-performance discrimination of signal between the two radiation types. Moreover the poor resolution makes the photon detection uninteresting for isotopic measurements in safeguards.

11. Training

The Euratom and IAEA inspectors are the main end users of the safeguards tools and technologies and need to have the best related training. In addition the present evolution of implementation of international safeguards asks for developing new training activities. Euratom and IAEA relies on a constant support from the JRC on training for inspectors which includes facilities for the use of both technical instrumentation and nuclear material. The different institutes of the JRC are involved in different areas of training, according to their respective scientific technical competence. There are nowadays at Ispra yearly about sixteen weeks of NDA training courses offered to Euratom and IAEA inspectors. This set of courses was recently extended with courses on Complementary Access and Design Information Verification and the Advanced NDA techniques. At the -analytical Laboratories in ITU – Karlsruhe specialized courses on the use of some measurement instrumentation are organised upon request. Training of IAEA and EURATOM inspectors in environmental sampling procedures is provided at ITU. This training is based on the rich experience available at ITU from particle analysis. Training on quality control on measurements are provided by the Institute for Reference Materials and Measurements.

12. Summary and Conclusions

The paper highlighted some new areas of research inside the European Commission – Joint Research Centre. These areas are highly focused on possible needs of both the IAEA and the European Commission's DG-Energy (implementing the EURATOM Treaty). As scientific results start to materialise it becomes easier to build working prototypes aimed at demonstration purposes. The dissemination of these results and prototypes will be done using the established channels, and in particular the European Commission Cooperative Support Programme to the IAEA [9].

Acknowledgments

This paper describes some of the R&D activities carried out by JRC in the context of the FP-7 2007-2011 Framework programme and results from the work of all researches and technicians working on it.

References

[1] http://cordis.europa.eu/fp7/home_en.html
[2] R. Schenkel and S. Abousahl "The Future of Nuclear Safeguards" Journal of Nuclear Materials Management, 2008, Volume 36, N°4, P47-52.
[3] M. Sturm, S. Richter, Y. Aregbe, R. Wellum, T. Altzitzoglou, A. Verbruggen, K. Mayer, T. Prohaska – "Feasibility study for the development of plutonium reference materials for age dating in nuclear forensics", IAEA Safeguards Symposium 2010, 1-5 November 2010, Vienna.
[4] R. Kips, M.J. Kristo, J. Crowhurst, I.D. Hutcheon, Z. Wang, T.J. Johnson, D.C, Gerlach, J.E. Amonette, K.B. Olsen, E. Stefaniak, Y. Aregbe – "Investigating Chemical and Molecular Changes in Uranium Oxyfluoride Particles using NanoSIMS and Mirco-Raman Spectroscopy", Proc. IAEA Symposium on International Safeguards, Vienna, 1-5 Nov 2010.
[5] Y. Ranebo, P. M. L. Hedberg, M. J. Whitehouse, K. Ingeneri and S. Littmann – "Improved Isotopic SIMS Measurements of Uranium Particles for Nuclear Safeguard Purposes", Journal of Analytical Atomic Spectrometry, vol. 24, No. 3, pp.249–356, March 2009.
[6] S. Abousahl van Belle, P.; Eberle, H.; Ottmar H.; Lynch, B.; Vallet, P.; Mayer, K "Development of Quantitative Analytical Methods for the Control of Actinides in a Pyrochemical Partitioning Process". Radiochimica Acta 93 (2005) 147-153
[7] S. Abousahl, H. Ottmar, H. Eberle, P. van Belle and R. Kristolaitis "New Parameter Values of Isotope Correlations for the Estimate of 242Pu"; Proc. 47th INMM Annual Meeting 16-20 July 2006, Nashville, Tennessee.
[8] S. Abousahl, H. Ottmara, P. van Bellea, Th. van Vuurea, K. Burke, J. Masonb, A. Tolchard, A. Towner "A combined calorimetry, neutron coincidence counting and gamma spectrometry system (CANEGA) for enhanced plutonium mass and isotopic assay"; Proc. IAEA Symposium on International safeguard, 16 – 20 October 2006 Vienna, Austria
[9] J. Gonçalves et al – "The European Commission Cooperative Support Programme: Activities and Achievements", Proc. IAEA Symposium on International Safeguards, Vienna, 1-5 Nov 2010.