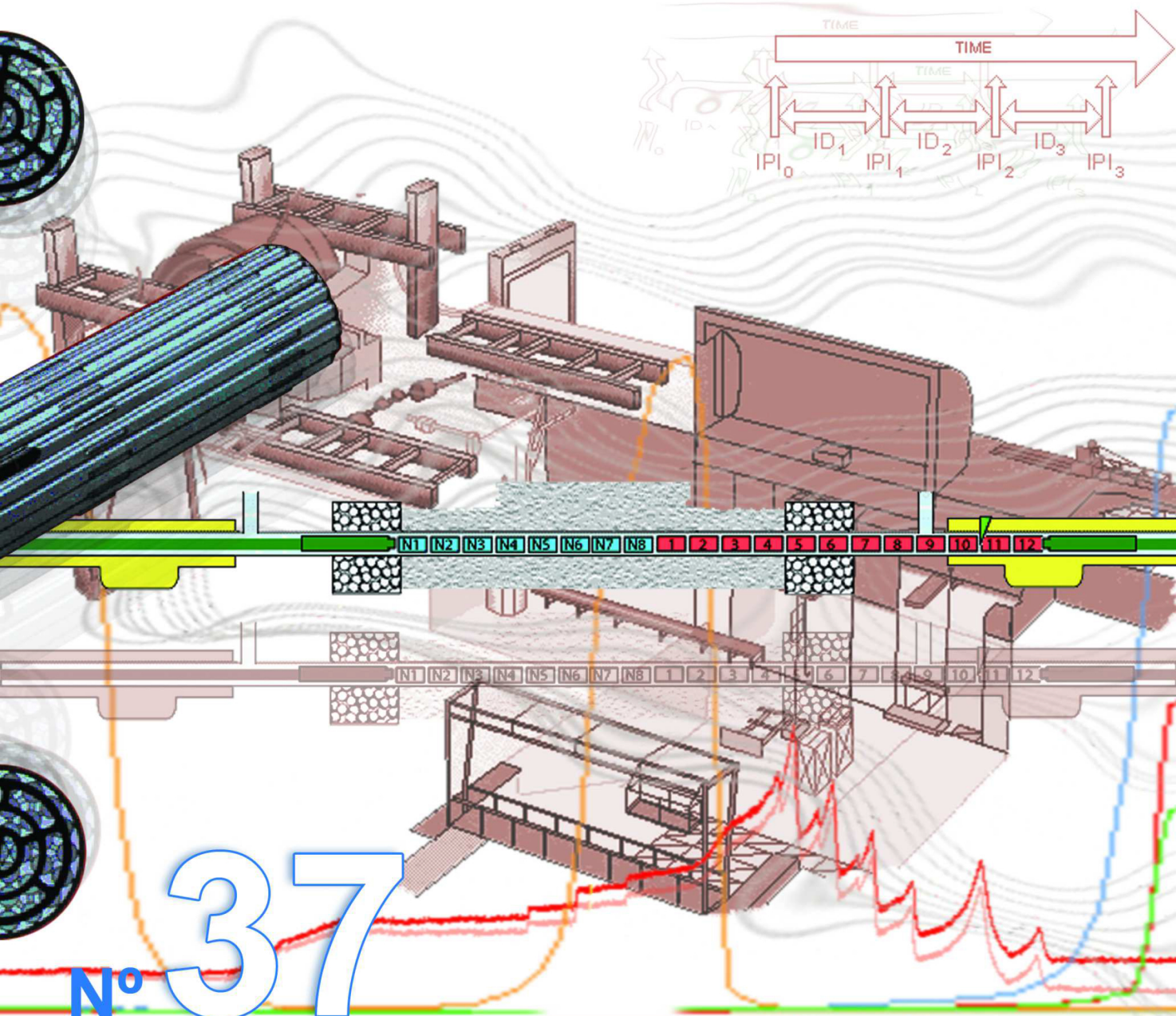




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Bulletin

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Editorial**Editorial**

by **G. Dahlin**, ESARDA President

I am glad to announce that, in 2007, six new members have joined ESARDA: the Romanian Regulatory Authority (CNCAN), Sellafield Ltd., the Swiss Federal Office of Energy and the Norwegian Radiation Protection Authority; Bruno Pellaud, former Deputy Director General of the IAEA Department of Safeguards, and Brian Burrows, former ESARDA President and Chair of the NMACAF Working Group, joined as individual members.

IRSN and ESARDA organised in Aix en Provence (France) in May 2007 the largest symposium ever in ESARDA history (260 participants, 150 papers, 30 sessions). At the symposium, new topics like export control as well as communication and training were addressed, together with matters relating to non-proliferation.

Regarding the 2009 symposium, I have received offers from two Parties of new EU member States to host the event.

ESARDA is now reaching the target of publishing the Bulletin twice a year. The section dedicated to peer reviewed articles has been in place now since two years.

With the years, ESARDA is therefore becoming more and more attractive.

The Nuclear Material Accountancy and Audit Focus Group (NMACAF), established for one year, delivered their results compiled in three reports. The summary and advisory reports are presented in this issue, preceded by an introduction into the role of audit in safeguards.

The European Commission DG TREN used the results when drafting the recommendations related to the audit part in the new document “Implementing Euratom Treaty Safeguards” (IETS). Currently, the recommendations are under discussion within member States and nuclear operators. For the implementation of audits in safeguards, discussions are now going on within ESARDA for creating a new Working Group to handle this.

In 2004, ESARDA decided to publish Technical Sheets on its website in the “Library” section. They are aiming at presenting in a few pages the basic principles, technologies or methods widely used in the fields of safeguards and non proliferation. The language is adapted to the targeted readers: students and interested public including media representatives.

In this issue, all the Technical Sheets related to NDA are presented as well as a couple of new C/S Technical Sheets. As a rule, all Technical Sheets are available on the ESARDA website.

The 2007 ESARDA training course was attended by 61 students, the largest number of participants since the establishment of the course. The students were encouraged to write an essay on a given topic relating to safeguards. Two of the best papers were selected for publication in this bulletin issue.

ESARDA News

Romanian Nuclear Regulatory Authority - Role and responsibilities

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Abstract

In accordance with the legal provisions set by the Law no. 111/1996 on safe deployment of nuclear activities, regulation, authorisation and control of nuclear activities, republished (as published in the Romanian Official Bulletin no. 552 /27.06.2006), the Romanian Nuclear Regulatory Authority is represented by the National Commission for Nuclear Activities Control (CNCAN).

CNCAN role and responsibilities are also established through the Governmental Decision no. 1627/2003 approving the CNCAN internal rules, with further modifications and completions.

1. Introduction

In Romania, the regulatory authority in the field of nuclear safety is the National Commission for Nuclear Activities Control (CNCAN). According to the legal provisions—Law. no. 111/1996 on safe deployment of nuclear activities, regulation, authorisation and control of nuclear activities, republished—as published in the Romanian Official Bulletin no. 552 /27.06.2006), CNCAN represents the national competent authority in nuclear safety field.

The Art. 4 of the above-mentioned law clearly underline that ***“The national competent authority in the nuclear domain that exerts the regulatory, authorization and control duties provided for in this law is the National Commission for Nuclear Activities Control, public institution of national interest, chaired by a President with the rank of State Secretary, coordinated by the Prime Minister through its Chancellory”.***

The financing of CNCAN is entirely ensured through extrabudgetary resources, while the fees for authorisation of activities are made revenue to the state budget. In accordance with the provisions of

CNCAN Internal Rules, approved through Governmental Decision no. 1627/2003 with further modifications and completions, the CNCAN organisational structure includes 171 positions, complying with the actual requirements on regulating the area and the Romanian nuclear power sector.

Through all its activities carried-out, *CNCAN comes forward as an independent authority, having its own, distinct and important part in assuring the strict observance of the nuclear safety and radiation protection requirements.*

2. CNCAN Organisational Structure and Human Resources

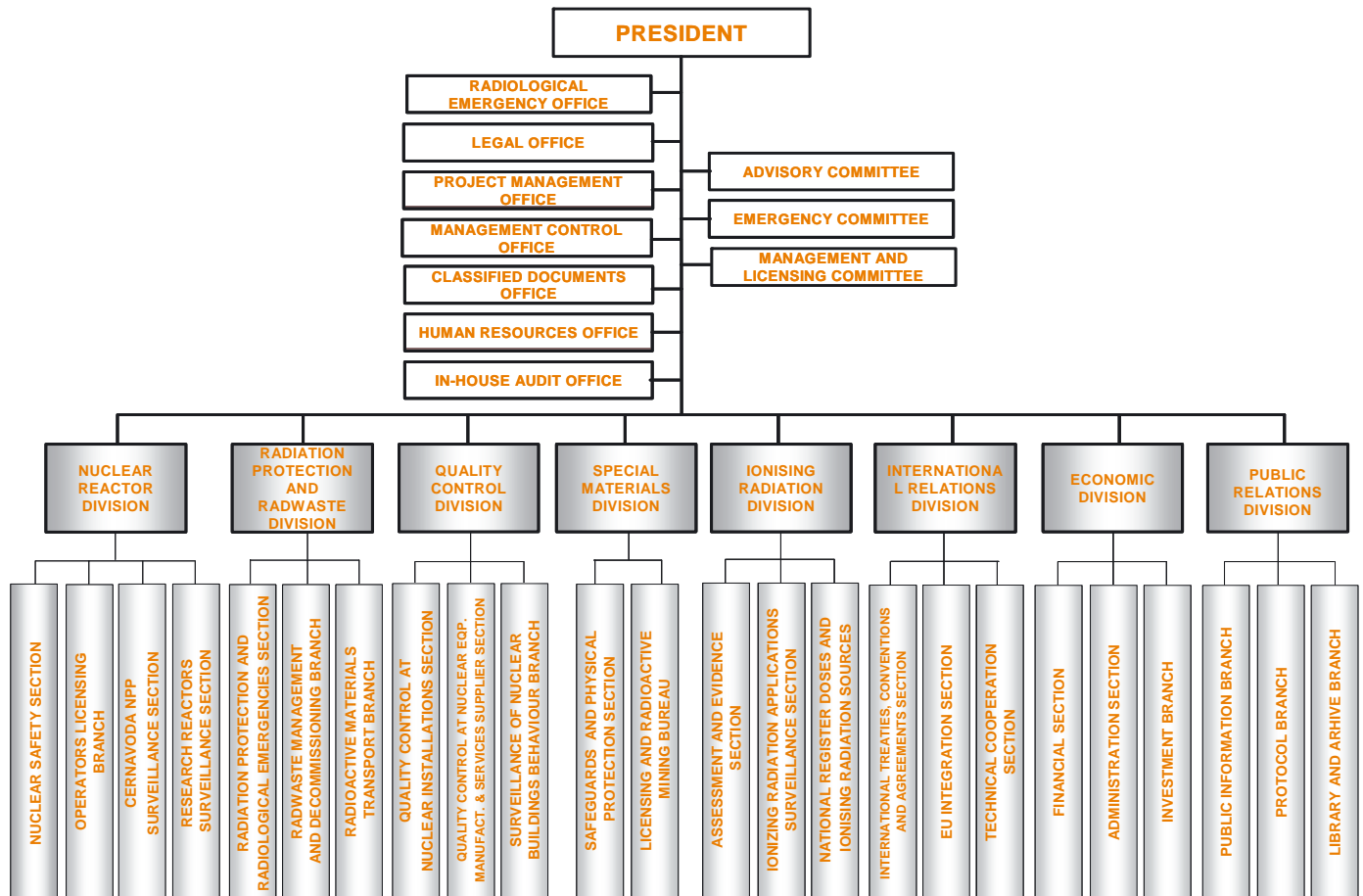
The President of CNCAN, with the advice of the Prime Minister's Chancellory, organises the subsidiary structures of the divisions of CNCAN depending on actual needs and conditions of the activities of CNCAN. The organisational structure of CNCAN and the modifications thereof are approved by Governmental Decision. The current organisational structure of CNCAN is shown in the fig.1.

The management of CNCAN is done through the Management and Licensing Committee. The Committee is formed by the President, the Directors of the Divisions and the Heads of the Sections and Compartments under direct subordination to the President.

The Management and Licensing Committee receives technical support from the Advisory Committee, formed by specialists in different areas relevant for the regulation and control of the nuclear activities. The structure and authorities/responsibilities of the Advisory Committee are approved by the President of CNCAN.

The organisational structure and staffing of CNCAN is properly arranged in order to cover with specialists all the assessment and inspection activities required

Fig. 1 CNCAN Organisational Structure



in all phases of a nuclear installation (site selection, design, construction, commissioning, operation and decommissioning).

The main Divisions involved in the regulation, licensing and control of Cernavoda NPP are:

- Nuclear Reactors Division;
- Quality Control Division;
- Radiation Protection and Radioactive Waste Division;
- Special Materials Division.

At present, the total number of staff positions is 171. The adequate number of staff was determined taking into account the work necessary to be performed, in different fields of activity. The new organisational structure, approved in 2006, corresponds to the new challenges in the field (such as the increase in the number of licence applicants, the commissioning for Cernavoda NPP Unit 2, etc.).

Adequate processes are in place to ensure that CNCAN staff is competent for the assigned duties. These include appropriate criteria for the recruitment of qualified personnel, as well as the continuous training aimed at maintaining and enhancing the competencies.





The recruiting process consists of a written examination and an oral examination/interview. The subjects chosen by CNCAN for the examinations are based on a complex bibliography, consisting of a variety of topics related to nuclear field, including both technical aspects and legislation in the domain. The examination board is formed by the senior experts from the top management level of CNCAN. CNCAN can also request the participation, as members of the examination board, of Professors from the Polytechnics University and the Faculty of Physics or other specialists in the nuclear field. In the process of hiring new staff, CNCAN takes into consideration the education of the candidates in the nuclear field of study and their performances, including diplomas/degrees and their background and working experience in the nuclear sector.

Training of the staff is recognised as vital and the necessary resources are devoted to it. This objective is achieved by using in-house training and also external support, especially through IAEA Technical Co-operation Programs or bilateral agreements. The job-related performance of all CNCAN staff is formally evaluated each year in accordance with CNCAN administrative policies and procedures.

3. Responsibilities

The experience of over 30 years in its field of competence contributed to the creation of a competitive and international recognised organisation with a key role in observing the compliance of nuclear safety and radiation protection requirements in Romania. The legislative framework observes the compliance of the provisions as stated by the art. 8 (2) of the Convention on Nuclear Safety by which the attributions and responsibilities of the nuclear regulatory authority are separated by those of the authority for promoting the peaceful use of nuclear energy.

The general attributions and responsibilities of CNCAN are stipulated in the Chapters I and V of the Law, and are further detailed in the Governmental Decision no. 1627/2003 with further modifications and completions. The mandate of CNCAN can be summarised as follows:

CNCAN is the national authority competent in exercising regulation, licensing and control in the nuclear field, for all the activities and installations under the scope of the Law.

CNCAN elaborates the strategy and the policies for regulation, licensing and control with regard to nuclear safety, radiological safety, non-proliferation of nuclear weapons, physical protection of nuclear installations and materials, transport of radioactive materials and safe management of radioactive waste and spent fuel, as part of the National Strategy for the development of the nuclear sector, approved by Governmental Decision.

CNCAN is responsible to ensure, through the regulations issued and the dispositions arising from the licensing and control procedures, that an adequate framework is in place for the deployment of activities under the scope of the Law.

CNCAN is responsible for revising the regulations whenever necessary for the correlation with the international standards and ratified conventions in the nuclear field and for establishing the necessary regulatory measures for their application.

The legislative provisions stipulated that CNCAN has also the following attributions in fulfilling its tasks:

REGULATIONS

- initiates and approves the legislative acts in its field of competence;
- issues guides, regulations, technical documents, standards and instructions governing the safe



operation of nuclear installations, protection of workers, public and environment against ionising radiation effects, physical protection, safeguards, transport, import, export and transit of radioactive materials, quality assurance, management of the radioactive waste and nuclear spent fuel, intervention in case of nuclear accident. **All regulations issued by CNCAN are approved by order of CNCAN President and are mandatory;**

- proposes the initiation of draft legislative acts in the field and approves all normative acts in nuclear field;

LICENSING

- issues authorisations and exercising permits for the activities developed in nuclear field;
- suspends or withdraw the authorizations, partially or totally, by its own initiative or at notification of any natural or legal person, in the case of non-compliance of the provisions of Law no. 111/1996 on safe deployment of nuclear activities, regulation, authorization and control of nuclear activities, republished;
- as result of the control performed, CNCAN may decide, as appropriate, the suspension of the activity developed and inalienability, by putting a seal, of nuclear and radiological installations, radioactive materials, nuclear materials or other materials, devices, equipment and information pertinent for the proliferation of nuclear weapons, or any other nuclear explosive devices, which are not authorized or might be dangerous during operation or possession;

CONTROL/INSPECTION

- establishes and co-ordinates the state system of accounting for and control of nuclear material, national system for accounting for and control of radioactive sources and nuclear and radiological installations and national dose register for occupationally exposed workers;
- organises, and is responsible for, state control concerning the non-proliferation of nuclear weapons, the application of the appropriate legal provisions to nuclear installations, during all phases of operation and in relation to all components of the quality assurance system in this field;
- reviews and assesses, from nuclear safety point of view, the documentation submitted by the authorization applicants;
- approves, according to the law, the intervention plans in case of a nuclear accident and participate in the intervention;

- verifies the compliance with requirements of regulations and procedures during the phases of design, construction, commissioning and operation of nuclear installations;
- collaborates with the central authority for the environmental protection and controls the activities developed by the National Radioactivity Surveillance Network;
- requests to the competent authorities in the field of national security to verify the personnel with responsibilities in nuclear activities;
- initiates, with the compliance of regulations in force, actions for the promotion of Romania's specific interest in relation with the International Atomic Energy Agency (I.A.E.A.), the Nuclear Energy Agency (N.E.A.) and other international organizations specialized in the field of regulations and control of nuclear activities;
- supervises the application of the provisions of international agreements in force on safety of nuclear facilities, safeguards, physical protection, interventions in case of nuclear accident and assistance in case of a nuclear accident;
- co-operates with other bodies which, according to the law, have powers in the field of safety operation of nuclear and radiological installations, in correlation with the requirements for environment and public protection;
- represents the national point of contact for safeguards, for physical protection of nuclear material, nuclear and radiological installations, for preventing and combating illicit trafficking of nuclear and radioactive material and for radiological emergencies;
- assures public information through official publications and press releases;
- decides the retrieval of orphan sources and co-ordinates the retrieval activities;

4. CNCAN Strategic Objectives

As national contact point for nuclear safeguards, CNCAN is responsible for monitoring the implementation of the EURATOM Treaty, especially focused on the nuclear safeguards. Through the Law no. 185/2007, Romania accessed to the ***“Agreement between the Kingdom of Belgium, the Kingdom of Denmark, the Federal Republic of Germany, Ireland, the Italian Republic, the Grand Duchy of Luxembourg, the Kingdom of the Netherlands, the European Atomic Energy Community and the International Atomic Energy Agency in implementation of Article III (1) and (4) of the Treaty on the non-proliferation of nuclear weapons (78/164/Euratom) adopted in Brussels, with subsequent amendments and to the***

Additional Protocol to the Agreement between the Kingdom of Belgium, the Kingdom of Denmark, the Federal Republic of Germany, Ireland, the Italian Republic, the Grand Duchy of Luxembourg, the Kingdom of the Netherlands, the European Atomic Energy Community and the International Atomic Energy Agency in implementation of Article III (1) and (4) of the Treaty on the non-proliferation of nuclear weapons, signed at Vienna on 22 September 1998". At the time being, in accordance with the provisions of Art. 23 within the above-mentioned Agreement, Romania notified to IAEA and to EC that were finalized all the internal procedures for entering into force of these acts (it is expected now, the official notification of the EC to the IAEA in order that they should produce effects for involved parties.

Generally, the activities developed by CNCAN on the basis of the following 8 action plans, aimed to a regular fulfilment of the objectives related to nuclear safety strategy and for the continuation of activities started within the EU accession process:

- Increasing CNCAN capability and independence level, as competent national authority for regulation, authorization and control of nuclear activities;
- Increasing of CNCAN sustainable participation in the activities dealing with safeguards aspects organised by the EC services
- Acceleration of revision and completion process of the legislative and regulatory framework within its competence scope;
- Investigation of locations with potential "orphan" radioactive sources and initiation and carrying out of corrective actions, depending on each situation;
- Increasing the technical performances and development of advanced administrative procedures with regard to systems for nuclear and radiological physical protection;
- Enhancing CNCAN capability with regards on early detection of potential events with consequences upon the nuclear and radiological physical protection systems;
- Development of CNCAN institutional cooperation, at national level;
- Strengthening bilateral and multilateral cooperation at international level with its competence area;
- Amplification of mass-media relations and appropriate public information

Implementation of safeguards in Spanish NPPs: advantages of cooperation and coordination

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Abstract:

In 2002 the Spanish Ministry of Industry, Tourism and Commerce (MITYC) informed the operators of the soon entry into force of the Additional Protocol (AP) to the Safeguards Agreement, once its ratification by the Member States of the EU were completed and the Community and national legislations were adapted to the new requirements.

The Spanish association for the electrical industry (UNESA) responded to that announcement setting up the UNESA's Safeguards Working Group (USWG), made up of staff of the NPPs in charge of nuclear material accountancy. The USWG was mandated to ensure coordinated implementation of the new safeguards obligation of the Additional Protocol in close cooperation with the Ministry of Industry, Tourism and Commerce (MITYC), Spanish authority for safeguards implementation follow up.

Although the group was initially meant only for NPPs, later on representatives of other main nuclear facilities (i.e. ENUSA's fuel fabrication facility, the national radwaste company ENRESA, and CIEMAT national research centre) have been also participating in the group's meeting and activities when general discussion points on the entry into force of the AP were dealt with.

From 2003 on, the USWG has met periodically with the aim of exchanging experiences in the field of safeguards implementation and jointly dealing with changes to EURATOM and IAEA safeguards systems lately introduced to reinforce their effectiveness and efficiency in response to the challenges posed to the international community by the recent discovery of undeclared nuclear programmes.

Along the operation of the USWG, presence of Spanish nuclear industry representatives in international fora dealing with safeguards has remarkably grown up. Moreover, representatives of

the USWG have also maintained an active participation in the ESARDA working groups on integrated safeguards (ISWG) and nuclear material accountancy and audit focus group (NMAC-AF).

Keywords: safeguards; audit; guidance; standard; additional protocol; accountancy

1. Foreword

The activation of the UNESA Safeguards Working Group (USWG) in early 2003 has proven to be a key factor for enhancing coordination among the main players of the Spanish nuclear industry and the Ministry of Industry, Tourism and Commerce (MITYC), the State authority for nuclear safeguards implementation follow up.

This improvement has directly translated into an enhancement of the quality of traditional nuclear material verification activities under "classical" EURATOM and IAEA safeguards, since the USWG represents a specialised forum where the staff directly in charge of safeguards implementation at the Spanish nuclear facilities meets to discuss in common safeguards matters and exchange operational experience. Furthermore, there is a regular presence of representatives of the MITYC conveying to the operators the latest developments in the international arena.

The main objective of the group is to agree on a common position and strategy to deal with matters such as:

- Entry into force of the Additional Protocol and site declarations
- New EURATOM safeguards regulation
- Changes to the reporting forms of nuclear material accountancy
- Changes to EURATOM safeguards approaches
- Introduction of auditing techniques to the operators' NMAC systems

The MITYC has strongly supported the activities of the group from its onset, in a moment of time when the MITYC was also reinforcing its organisation to face the new State responsibilities stemming from the Additional Protocol and increasing the resources devoted to follow up safeguards implementation in the Spanish nuclear installations, as well as in the international arena.

2. Organisation and main activities of the USWG

The USWG is an industry framework meant to discuss, deal with and exchange operational experience on safeguards implementation in major nuclear facilities. The group is composed of representatives of the NMAC organisations of the Spanish NPPs, one of them serves as coordinator. Meets periodically, normally every three or four months, and when the need arises to deal with urgent matters or to discuss exceptional operational events in relation to safeguards or accountancy. Representatives of the MITYC regularly attend the meetings.

So far, the meetings are held in the premises of UNESA in Madrid or at the headquarters of the MITYC when the group is called to discuss official subjects or to meet with EURATOM or IAEA representatives. However, there are future plans to hold some of the meetings in the nuclear facilities in order to facility a larger involvement of the all the nuclear material accountancy staff in the activities of the group.

After the meetings, the coordinator produces the minutes for comments and the approved version is delivered to the plant managers and to UNESA's secretary to have informed the representatives of the utilities and give visibility to the work of the group.

Among the most relevant past activities of the group stand out the preparation of the first site declaration for reporting under the Additional Protocol, the development of a UNESA's guide for handling complementary and managed access (to be further specified and shaped by each facility) and more recently the development of a software tool meant to help the operators to produce the periodical accountancy reports to EURATOM under XML format, as required by the new 2005 Community's safeguards regulation.

2.1. Entry into force of the Additional Protocol

The first reporting obligation of every nuclear site under article 2.a.ii of the AP is the site boundary

definition and the description of all the buildings on the site. The MITYC channelled through the USWG the coordination for preparing the site declaration of the Spanish nuclear installations under CAPE format (software application developed by the European Commission for reporting AP-related obligations).

Common criteria were established for site boundary definition. For instance, the security double fence of the territory under the operator's control was chosen as site boundary of the NPPs and similar scope and content of the information describing buildings were included in all the declarations of the NPPs. Buildings outside the double fence were separately listed but not included as part of the site. Later on each installation reported directly to the EC in CAPE format.

A similar procedure was followed for the site definition of the fuel fabrication plant and the low and medium level radioactive waste plant. The case of the CIEMAT research centre was dealt with separately due the peculiarities of the site, in which nowadays there are many buildings with no nuclear use and the territory is split in two nearby separated areas crossed by a road.

The exchange of experiences among the operators at the stage when CAPE inputs were first created, applying similar rules for the definition of the buildings within the site following. was decisive to table on time a set of uniform declarations for all the major Spanish nuclear installations. In fact, the review of the information made by the Commission services confirmed that the quality and punctuality of the declarations was rather satisfactory.

In parallel, other AP-related subjects were discussed by the USWG. In particular, a number of concerns were brought up on how to manage, from a security perspective, prompt access of safeguards inspectors to the sites and to any place within the sites during complementary access, the availability of personnel for escorting at any time the inspection team throughout the site and the implications of IAEA inspectors taking pictures from both security and industrial property rights perspectives. Again the USWG decided to face these issues together in order to follow the same approach in all the nuclear installations and eventually draft generic procedures to be further shaped by each facility.

The subject of picture-taking during AP complementary access was especially difficult, since Agency's interpretation of the AP obligations entered, to a certain extent, in conflict with physical protection obligations mandated by the Spanish regulations. The introduction of cameras in Spanish

nuclear facilities was forbidden well before this subject was first brought up by the Agency upon the argument that the meaning of “visual observation” in the AP includes the use of cameras. Taking this on board, the final agreement reached at the USWG was that pictures would be taken only by the operators themselves, using their own cameras, under IAEA’s request and that the pictures will be later screened, picture by picture, either to grant free release or to put them under IAEA seal at the plant for future consultations. Pictures screened for free release were handed over to the IAEA and the Commission upon the signature of a safeguards confidentiality undertaking. Furthermore, picture-taking during routine inspections was not foreseen in the procedure, except in well justified cases and upon prior notification to and acceptance of the Spanish authorities well in advance of the inspection date.

The entry into force of this procedure was initially contested by the IAEA inspectors in the first complementary accesses triggered to Spanish nuclear sites and in some case a second review of the pictures screened out by the operators was needed in the presence of State representatives to mediate. Nowadays the procedure is well established and no further problems have been raised so far.

2.2. New EURATOM safeguards regulation (302/2005) and approaches.

2.2.1. Changes in nuclear material accountancy reports

The new 2005 Euratom safeguards regulation has brought important changes to the form and content of the nuclear material accountancy reports to be sent periodically to the European Commission, as well as to some of the accountancy criteria followed under the old regulation. Even though the regulation established a transitional period to give time to the operator to adjust their practices and plant procedures, the impact of the changes are not negligible and the software tools in use at the larger installations have to be updated.

In 2006, at the request of the Spanish operators, the EC organised a seminar at the premises of the MITYC to give full explanation of the changes and to discuss the application of the new reporting rules to a number of concrete examples. The Commission also expanded on the features of the new ENMAS software, designed to help the operators to prepare the reports, both in its full and light versions.

This subject was particularly relevant for the Spanish operators, since the variety of designs and

ownerships that can be found among the Spanish plants, together with the lack of uniform Community’s guidelines under the old regulation, had made that every plant were using different software applications and in some cases even following different criteria. In view of this situation, the USWG entrusted the coordinator of the group with the task of participating in several trial exercises using the new software in order to gain experience and later to share it with the rest of the group’s members.

From the very beginning, use of ENMAS-full was left out by the Spanish operators due to its excessively broad scope. On the other hand, ENMAS-Light, being a much better appropriate tool, raised also some difficulties. This piece of software has been designed to import data files written in its own native XML, forcing the operators either to implement important changes to their data management systems or to introduce many entry lines with accountancy information by hand, something unaffordable to the small-sized nuclear material accountancy units of the NPPs.

On the other hand, changes to the different accountancy software applications and procedures in use in the NPPs in order to fit them to the new requirements and reporting forms is not an easy task. On the contrary, it is a long and complex process, sometimes underestimated by those who are not directly involved in nuclear installations operation. First, there are several players involved: information, nuclear and quality assurance staff. Second, nuclear material accountancy data is many times interwoven with safety-related information. For instance, nuclear material data is used to verify correct core loading from a safety standpoint or to check compliance with criticality safety requirements. Last but not least, changes in NPPs’ procedures, including software changes, require a rigorous internal review and approval process, which potentially may also require regulatory review in cases where there are safety-related implications affecting either license conditions or regulatory obligations.

Taking these difficulties on board, the Spanish operators were afraid of not being able to complete these procedures in time and decided to follow a less burdensome and costly way forward. Through the USWG, a universal bridging software module has been developed in order to prepare automatically the files in the same XML format required by ENMAS-Light taking the nuclear material accountancy information provided by the nuclear data management systems of the NPPs. The functional design of this software application, called

EurReports, has been build upon an Access database, containing individual tables with the fields required by each accountancy report (annexes of the regulation), which has to be filled in by the nuclear material accountancy applications of the nuclear installations. Once each table is completed, the application converted it to a XML file to be later on imported by ENMAS-Light. Furthermore, the validity of most internal coding is checked and finally the CRC is calculated and filled in the form of a file directly usable by EURATOM, giving so assurance to compliance with the basic rules for reporting, and, remarkable enough, generating the redundant verification code of each entry line (CRC code) making use of the algorithm embedded in ENMAS.

EurReports application (executable, source code and associated database) has been distributed to the members of the ESWG for free use and adaptation to each nuclear material accountancy system of the installations. With this tool the use of EURATOM software is more effective and there is no need for implementing drastic changes to the nuclear material accountancy software tools in use at the plants. Moreover, an external application can be developed to read the existing nuclear material accountancy database and filling in EurReports table without changing at all the original source code.

2.2.2. New safeguards approaches:

Use of audits as an inspection tool

In coincidence with the last EU enlargement, the EC embarked in a reform of Euratom Treaty safeguards aimed to optimise the use of resources by enhancing the quality of its inspection activities, while not diminishing the effectiveness of the current system. Against this background, the EC decided to apply a methodology similar to that of quality assurance audits to review the nuclear material accountancy systems of the operators. To this end, the ESARDA working group on Nuclear Material Accountancy – Audit Focus (NMAC-AF) was set up in 2006 with the mandate of carrying out an assessment on how the quality assurance methodology can be imported in an efficient way to the safeguards field.

The NMAC-AF group is composed of specialists from Member States coming from different type of nuclear installations, including NPPs, fuel fabrication and enrichment plants and radwaste storage plants, as well as representatives of regulatory organisations. The USWG considered the scope of the work to be done by this new group as very relevant, taking into account the potential impact on the operation of the installations, and proposed the MITYC to designate

to his coordinator as member of the newly created working group. After one year of heavy work, the NMAC-AF, chaired by Mr. Brian Burrows, produced a set of outstanding documents presented at the 2007 ESARDA conference, which were highly appreciated by the audience. The top document is a comprehensive paper with recommendation both to the operators and the EC, which was accompanied by generic guidelines to be applied to the various types of installations describing the key features that a good nuclear material accountancy system should have. This set of documents is intended to fill the existing gap of quality standards specifically devoted to nuclear material accountancy audits and to provide the EC reference guidelines to develop its own recommendations on how to implement an adequate nuclear material accountancy system in a nuclear installation.

The MITYC was very satisfied of the work and outcome of the NMAC-AF and suggested to the USWG offering some Spanish nuclear facilities as candidates to carry out audit field trials based on the guidance produced by the NMAC-AF. The proposal was seen with very good eyes by the Spanish operators, which offered Asco NPP and Juzbado fuel fabrication plant to host these field trials.

Meanwhile, the USWG has already started to study the documents delivered by the NMAC-AF in order to fit the procedures and organisation of the installations to the recommendations in this guidance.

2.3. Spanish participation in ESARDA working groups

For many years, the CIEMAT (Spanish research centre for energy and environmental technology development) was official member of ESARDA and had an active participation in many activities and working groups of the association. However, after Spain joined the EU in 1986 the national regulatory infrastructure for following up international safeguards commitments started to be partially dismantled. The Spanish Government decided to fully rely on the EC to liaise with the IAEA in accordance with the INFCIRC/193 safeguards agreement. The remaining part of the national safeguards infrastructure was transferred to the ministry responsible for energy matters (nowadays the MITYC), mainly to exercise Government representation in front of EURATOM and the IAEA. As a result of this change in the national policy, the participation of CIEMAT in safeguards development projects progressively diminished and, consequently,

decided to quit ESARDA. A number of years followed without official Spanish membership in ESARDA, although some residual participation in several working groups was always kept. Since early the 2000s, when the preparation for the entry into force of the Additional Protocol in the EU was more deeply discussed, Spain resumed a stronger participation in ESARDA activities and in 2006 the MITYC applied for and was accepted as official member of the association.

Nowadays, there is Spanish active participation in two ESARDA working groups, the said NMAC-AF and the Integrated Safeguards Working Group (ISWG). As it has been mentioned before, the USWG has one permanent representative in the NMAC-AF, while the Spanish representation in the ISWG is mainly held by the MITYC due to its more policy-oriented nature. However, the MITYC many times request the participation of industry representatives, in most cases from Juzbado fuel fabrication plant, in the meetings and activities of the group when deemed worth to deal with more pragmatic matters of safeguards implementation.

Meetings of the USWG are seized to debrief the operators on what has been discussed in the framework of the ISWG; sometimes to build up a common position when the matters have a direct impact on plants operation and other times to complete actions proposed by the USWG that require information or opinion of the operators.

2.4. Exchange of operational experience in the field nuclear safeguards application.

For many years, apart from the activities promoted through ESARDA, there has not been any official forum where safeguards operational experience could be discussed among the operators, as well as promote a solid safeguards culture. The operators feel many times isolated, unable to discuss in common with other colleagues safeguards operational matters that are relevant to the operation and economy of the plants, as well to ensure effective and efficient application of EURATOM and IAEA safeguards.

Against the background of the reform of EURATOM Treaty safeguards, the EC has organised several seminars, in which the operators have had the opportunity to sit together and exchange their views and experiences. However, the situation is still far from what would be expected for a fair regulatory system compare to other fields of the nuclear industry, like safety, radiological protection, physical protection, etcetera, in which the national regulators

are much closer to the operators than the EC, not to mention the IAEA, which incontestable rules and decisions fall many times out of the blue on the operators shoulders. As in any other field under regulatory oversight, the first commandment of a fair regulator, many times forgotten, is to communicate and make understandable his decisions to those subject to regulatory obligations.


The fact remain that after 50 years of EURATOM Treaty, the only safeguards regulation in force is the recently revised regulation on nuclear material accountancy, but apart from that there is no guidance for inspection, education, training... Only very recently the EC has initiated consultations on a new recommendation for the application of audit techniques to nuclear material accountancy, which promises to be a positive step forward in the right direction. However, a more stable frame, with periodically meetings of the operator at Community level would be certainly beneficial and should be promoted by the EC.

Meanwhile, this deficit can be, to a certain extent, compensated with the work of operators' group like the USGW. The discussions within these groups may serve to reinforce the individual know-how from others experience, to prevent conflicting situations during inspections, to avoid operational mistakes, to develop procedures and tools, etcetera. Although the USGW was only set up in 2002, as of today it has already delivered tangible products to the Spanish operators, as those explained in this article, but also less tangible benefits but not less important, like a substantial gain of visibility in the eyes of plant managers of the nuclear material accountancy and safeguards work.

3. Conclusions

The USGW has proven to be a very valuable tool for the operators jointly asses and deal with new challenges in the ever changing arena of the international nuclear safeguards, particularly now that the EC and the IAEA have embarked in a broad reform of their respective safeguards systems.

Furthermore, the support and engagement of MITYC officers responsible for safeguards implementation follow up in the activities of the group has doubled its value, since it represents a two-way specialised forum through which the State can disseminate information or policy guidance, as well as receive opinion from the operators that can be later on taken on board to build up a national position.



Over its few years of existence, the USWG has delivered valuable tools, like the UNESA guide on complementary access management and the software application EurReport to adapt the nuclear material accountancy management system of the plants to the requirements of the new 2005 EURATOM regulation. Even more important is that through the work of the group safeguards are now much better understood and respected by the Spanish nuclear community.

Sellafield Ltd

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Sellafield Ltd

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Sellafield Ltd has a proud heritage which includes the development of the world's first commercial nuclear power station. It has emerged from the re-organisation of the UK's nuclear assets and liabilities as the company responsible for the safe delivery of multi-million pound contracts on behalf of site owners, the Nuclear Decommissioning Authority (NDA). Our experience in the nuclear industry remains as strong as ever. Experience delivered through a skilled workforce who continues to operate our sites with the utmost safety and ever increasing levels of efficiency.

There are three business elements of the company:

Sellafield operations

- Remediation, decommissioning & clean-up of historic legacy plant
- Reprocessing, MOX manufacture and waste management

Capenhurst operations

- Decommissioning & dismantling historic enrichment plant

International Nuclear Services

- Commercial and contracts management for nuclear fuel recycling
- services, products and the associated transport
- Business development for used nuclear fuel management, waste management and nuclear materials transport

Sellafield

The Sellafield site, covering an area of approximately 4 square kilometres on the West Cumbrian coast just north of the village of Seascale, represents the most challenging nuclear site management programme in the world.

Managed and operated by Sellafield Ltd on behalf of the NDA, activities centre on remediation, decommissioning and clean-up of the historic legacy. The site is also home to the Thorp and Magnox reprocessing plants, the Sellafield Mixed Oxide Fuel manufacturing plant and a wide range of

waste management and effluent treatment facilities.

The primary objective at the site is to continue to manage plant operations and an extensive clean-up and decommissioning programme.



Capenhurst

The team at Capenhurst is focused on the safe and efficient decommissioning of a redundant enrichment facility and associated buildings, also on behalf of the NDA. Sellafield Ltd holds the site licence and as the Site Licence Company manages the day-to-day decommissioning operations on the Capenhurst site.

Capenhurst also houses modernised and upgraded facilities in the former diffusion plant to store uranic materials prior to their long-term re-use within the nuclear fuel cycle.

INS

International Nuclear Services manages the contracts and logistics for nuclear fuel recycling

products and services for UK and overseas customers. They are 51% owned by Sellafield Ltd and 49% owned by the NDA. The main focus as the customer interface to over 20 utility customers for reprocessing and MOX fuel supply contracts, and the associated transport of these products is to endeavour to meet customer's needs to exacting standards of quality and safety. Recently the UK government approved the transfer of INS to being a 100% NDA owned interest and this transfer is scheduled for April 2008.



Working Group activities

The role of Safeguards Audit in Quality Assurance.

Brian Burrows

Chairman of the Nuclear Material Accountancy and Audit Focus Group

It was my pleasure as Chairman of the ESARDA NMAC and Audit Focus Group to briefly summarise the work of the group in the last ESARDA Bulletin, No 36. I indicated that the output of the group needed to receive a wider consensus and that the ESARDA executive has approved making the documents available on the open area of the website. The main report is entitled “NMACAF advisory report” and was issued with two associated companion reports. The first was a straightforward extract of all the group’s suggestions and the second was a brief executive summary of the main report. These companion reports are published here in this bulletin and this is my short introduction for them.

I have chosen the title very deliberately in order to illustrate the perceptions at the core of the audit issue. Consider reversing this title to “the role of Audit in Safeguards Assurance”. In other words, is audit a part of a voluntary improvement process which installations should embrace or is it an addition to the policeman’s toolbox?

The English poet John Milton has a verse which refers to the comfort of what one knows well “I know

each lane and every alley green --- my daily walks and ancient neighbourhood”. To many, the emphasis on NMAC audit as something new and substantial has been confusing and has switched on the “just say no” neuron circuits which react to danger. DGTREN’s proposed use of audit was initially greeted with great suspicion. There was a determination to prevent the burden on operators increasing and to protect the achievement of safeguards assurance using physical inspection. More helpful and challenging is to see audit as a tool for self-examination, continuous improvement and quality assurance. The Japanese have a strategy of “kaizen” (continuous improvement) that starts with goals that are moderate and gradually rise to the challenge as the process continues. If TREN follow this gentle process it will motivate and yet still give visible progress whilst managing the effort for all involved. DGTREN can stimulate a broader need for achievement and self control; this is the better framework for audit. What we must surely all agree on is that sound safeguards conclusions can only come from properly controlled and timely NMAC processes.

Nuclear Material Accountancy and Control Audit Focus Group (NMACAF) - Working group advisory report. Summary of the principal advice

Brian Burrows

Chairman of the NMACAF working group.

1. The NMACAF working group

This was formed as a topical working group for the duration of approximately one year in order to consider and advise on the use of audit and quality assurance by Euratom safeguards inspectors. The group's terms of reference included consideration of:-

- An appropriate reference against which the Commission could audit NMAC systems;
- The usefulness of ISO certification/accreditation for NMAC system assurance;
- The modalities, process & tools available for conducting, reporting and evaluating audits;
- How audit results might complement inspection activities and future safeguards approaches;
- The advantages/disadvantages of audit and how this could impact on physical verification;
- The need to scale audits proportional with material holdings, facility types, maturity and transparency of existing systems and operational performance.
- The need for flexibility and overcoming the barriers to its use, including appropriate competencies and training.

The working group has delivered three outputs. Firstly, a guideline reference for good practice NMAC, against which to audit. Secondly an advisory document on the concepts and general implementation of audit, and thirdly a guideline on the conduct of safeguards audits.

As broad a range of contributions as possible was encouraged but the group had limited input from the IAEA and new member states. The interest from the nuclear weapon states was high especially given the trial safeguards audits being conducted in 2006.

The advisory report was produced collectively by the active members of the working group. Their contributions have been provided in their individual capacities and therefore the expert views expressed are purely those of the writers. The report does however include an annexed statement from Urenco, expressing that organisation's collective position.

The group did have conflicting views and even a definition of safeguards audit was a matter of some dispute. The advisory report therefore is extensive in documenting the groups various views but not all the suggestions presented can be considered as unanimous. The advice is presented here in sections 2 & 3 below concentrating on the issue of audit and then the issue of NMAC quality.

2. Legality, proportionality, universality, productivity, reality, utility

There were diametrically opposite positions in the group as regards the legality of the use of audit by safeguards inspectors. From either requiring a new legal instrument/modified PSPs to being entirely within the remit of current legal instruments. The consensus was that this was not a yes/no situation but a matter of gradient and of case by case assessment. It is not appropriate for the group to second guess on this matter and it recommends the Commission to consider its legal stance.

- Commission legal service should be consulted to determine whether the Commission has the legal right to audit (3.3.1).
- Where performance issues are protracted or systemic, then the Commission should, as part of due process, offer to the operator the option to allow a full system audit before assessing whether to proceed to any sanction action, thus taking an educational rather than punitive approach to enforcement where possible (3.3.3).
- PSPs should not be modified to accommodate audit requirements unless this is a specific request by the operator/member state (then consider application to all installations in that member state) (4.4.2).
- Special reports may include requests for further information of an audit and quality nature where procedural or management defects are possible root causes of the incident (4.4.3). Significant events are best dealt with in the first instance using the special reporting requirements. Audit can then proceed without disrupting investigations and can focus on root cause identification and

the appropriateness and completeness of corrective actions (6.1.5).

- The legal framework does not require specific competencies for inspections/audits (6.2.3).
- The adequacy of the NMAC system may be judged against the ESARDA guideline but divergence from that guideline cannot solicit non-compliance actions (6.4.2).

Whilst member states may have come to some accommodation on the Framework for future Euratom inspection activities, an operator is only formally bound by the current legal framework. Audits are an additional cost and operators in the older member states see that given a known good track record then audits are not warranted and are disproportionate to any perceived benefit.

- Audit could be implemented with a code of practice and in accordance with the principle of proportionality. Proportionality should be applied on a case by case basis. Installations with good performance and compliance should be able to reject audits if the burden (cost) is disproportionate to the benefit (a contribution to EU safeguards assurance) (3.3.1)
- Audit is not justified where an installation has had extensive BTC verification, has been subject to routine inspection and has had no significant or persistent performance issues. (3.2.1)
- Large scope audits should be used sparingly and only where interactions are complex or performance warrants it or there is significant change or organisational turbulence (3.1.1)
- Audits, consisting of more comprehensive measures than carried out in physical verification should be an additional tool for the evaluation of irregularities or inconsistencies (6.1.1).

Assessment at least every 24 months is not feasible if this translates to the universal application of audit. Auditing must be targeted and applied consistently, equitably and pragmatically.

- Audit modalities should be made transparent to all member states and operators (6.4.4)
- Annual assessments should give rise to annual audit plans and both should be conveyed to the operators (3.4.8).
- Highly performing installations should have limited audit. A greater weighting could be given to the results of other audits to limit safeguards audits to a very low frequency (6.1.3).

- The Commission needs to be pragmatic about compliant measurements in old bulk handling plants (3.5.1) and about scheduling audits around workload peaks of the operator (6.1.2)
- Bulk handling processes are best suited to substantive NMAC audit (4.6.1) and major audits are appropriate at the beginning and end of a bulk handling plant's lifecycle (4.6.4).
- A limited approach should be used for small facilities by random selection from a group (4.6.2). Special arrangements can deal with minimal procedural systems and the vulnerability of reliance on people and not on systems (3.5.6).
- Tailor audits for centralised organisations & for highly automated installations (4.6.5&6).
- An assessment programme should form the basis for the frequency & type of audits (6.1.2).
- Systems audits are the same irrespective of the strategic nature of the materials. They focus on a system and people perspective and ensure compliance and conformity (3.5.7).
- Performance and credibility audit must vary in line with the proliferation sensitivity of the material and must include all safeguards in depth features (3.5.7).

Specific reductions in inspection activity as a result of audit are not readily apparent but audit could improve inspectors' productivity and increase safeguard credibility due to better targeted inspections. Joint team inspections however require that the IAEA be convinced of the usefulness of audit. The aim of both inspectorates is to strengthen the effectiveness and efficiency of safeguards.

- Trials must be extended to gauge the impact on, and potential inclusion in, integrated safeguards (7.1.3).
- On a short and medium term basis, the Commission should not further reduce its inspection frequencies as a result of audit findings so as to guarantee the existing credibility on nuclear safeguards (7.1.4).
- Audit trials and experience in addition to well formulated criteria for assessing confidence and risk need to be in place and transparent to operators and member states before significant changes to the inspection mix take place. The Commission should set itself a time limit to gather such information and formulate its methodologies (7.1.4).

- There is a need to formalise the process for marrying inspections and audit findings, and deriving a confidence level which could influence inspection activities towards a (pre-) defined minimum credible level (6.4.3).
- Audits should be evaluated against known objectives and perceived added value in order to determine whether to continue or discontinue the audit approach (4.1.5).

The reality of the situations is that audits can consume some 3 times the personnel days of inspection (PDIs) as normal inspections, unless some efficiency measures are deployed. In real terms this means taking a more flexible and less independent approach and working with what an operator or state already has in place.

- State authorities should take part in the Euratom safeguards audits and follow up. Member states should progress the follow up and could share the results with the Commission (4.3.2).
- National NMAC regulations/standards could be used in Commission NMAC audits (4.3.3).
- An appropriate secure protocol is required for information supplied for remote desk top compliance audits. Information should be returned or destroyed in a prescribed time (4.3.4).
- The Commission should consider using/endorsing national quality assurance programmes (4.3.5).
- Where an operator can prove (via evidence) that his accounting system is reliably checked on a routine basis by audits/inspections of third parties and its qualification (ISO certified or accredited) is maintained, those audit results should be viewed, relied on and accepted by the safeguards inspectorates (4.2.1).
- Potential improvement may be achieved by partially moving from classical inspections of products or status to system verification and evaluation. It is mistaken to replace the term “inspection” by “audit” (4.6.9).

The use of audit has most utility when it fuels continuous improvement (which is a voluntary operator process) and when it provides positive endorsement:-

- Performance and quality assessment can be within normal inspection monitoring. More substantive reviews should be conducted as part of a collaborative framework of peer review of

the operator’s system and to encourage continuous improvement (3.3.2).

- As quality is closely tied to continuous improvement and not simply regulatory compliance, the Commission auditors should approach audits in a spirit of collaboration and employ a different cultural approach to that used for physical inspections (6.2.2).
- Operators should be encouraged to voluntarily go beyond the confines of the regulation in order to show active quality management (3.4.1).
- WANO (World Association of Nuclear Operators) style audits are conducted in a confidential voluntary framework and are a model for peer review having clearly defined criteria and performance objectives. The synergies for use in safeguards audits should be explored by the Commission (4.2.5).
- The Commission should give a positive endorsement in their audit findings when appropriate and should give credit to operator’s investments, achievements and accreditations (3.5.8).
- The Commission should be transparent about its audit activities and the effect on personnel days on inspection (PDIs). The degree to which installations have volunteered for audit, beyond the scope of the legal requirements, should also be made clear (3.4.6).

3. Quality, guidelines, measurements, performance, benchmarking

The Commission task is not a relatively simple one of monitoring and checking compliance with a centrally defined NMAC standard but rather understanding and trying to find common NMAC principles and processes across a large number of widely-differing systems. The process for achieving quality is identifying the risks that the NMAC activity runs of not being successful, managing the control practices that eliminate those risks and having objective measures of performance and underpinning evidence.

- The Commission should seek to ascertain proof that quality is being managed with particular emphasis on internal NMAC controls and on response systems (6.4.1).
- NMAC audit requires an appropriate reference to audit against. Presently, no ISO standard is completely congruent with the requirements of Regulation 302/2005 (4.1.2). The Working group

has consequently developed a reference guideline for good practice NMAC that may be used as an appropriate tool for considering NMAC quality issues during safeguards audits (5.1.3).

- The guideline for best practice NMAC is a live document to be refined. Reviews need to take into account the work of the INMM WINS project and the IAEA nuclear material accountancy handbook. These should be in harmony and ultimately congruent (4.5.5).
- Given an increasing importance of quality matters in the EC safeguard approaches, it is important to avoid confusion over terminology (4.1.1). Consistent and high quality use of NMAC and audit terminology should be supported by a terminology database (6.3.3).
- Installations will be free to choose whatever technical solution best fits their plants but should be encouraged towards harmonisation with key elements of the NMAC guidelines (4.5.1). For new plants this is the most opportune and least costly time for NMAC systems to take onboard the guidelines for good practice (5.1.4).
- Each installation should be encouraged to harmonise NMAC system processes across its operating and business units so as to reduce complexity, enhance technical integrity, increase transparency and better enable efficient audit (4.5.2).
- It would be good practice for operators to have a concise statement of the NMAC implementation model and how and where it overlaps with installation quality management processes. This is preferable to expanding the regulation companion guideline for what is expected in the BTC for a description of the accountancy system. Operators should also consider self assessment against the guideline (4.4.1).
- Since good practice can only be 'voluntary', then the Commission should accept and record the operator's rationale as to why a particular good practice should not apply in their particular circumstance (4.6.7).
- It is to be explored whether the NMAC guidelines can be laid out in a pattern tailored to specific plant types (as in the BTC). Special annexes should be created if specific fuel cycle or nuclear activity warrants it (e.g. research installations). The NMAC guidelines do have an annex for NPPs (4.6.8) in anticipation of and preparation for new reactor build.

The main tool for assessing NMAC performance will continue to be the material balance; the completeness and correctness of flow and inventory data and the installation's measurement capability (bulk handling) and tracking capability (item handling).

- The ISO standards (ISO 17025 and 10012) which relate to measurement systems and specific aspects of measurement (ISO 5725, 5479 etc) together with international target values should be the basis for making a qualitative assessment of the NMAC measurement system (4.1.3). This should not require state of the art measurement technology for all instances, but should take into account plant specific requirements and commercial aspects. By accommodating these plant specifics, it can be determined whether highly sophisticated measurement techniques are needed to achieve the required level of analytical accuracy (4.5.2).
- Good practice in the sense of target values may be defined for measurement/analytical methods and possibly for specific NMAC in selected sections of individual plants (4.5.4).
- The Commission needs to establish with each operator, equitable target benchmark values for NMAC accuracy and timeliness and for detection capability (quantity, detection probability, detection time) appropriate to the installation and material type (5.3.2) and should benchmark an installation across its own operations and performance history (5.2.3).
- It would be useful if the Commission could devise a clear methodology of rating and assigning a confidence level to an NMAC system (5.3.5).
- The Commission should not seek to impose performance levels for which the NMAC system was not designed (5.3.2). A high standard of NMAC measurements is only necessary in bulk handling installations, where high measurement accuracy contributes to achieve acceptable MUF and SRD (3.5.1). The operator's accountancy systems in bulk installations however can not be expected to detect the removal of a small quantity of material or provide a fast enough response to be useful in helping prevent theft or diversion (3.5.4).
- Complementary safeguards tools (and other features providing safeguards in depth) should also be included in the audit evaluation of performance as these often compensate for unavoidable or inherent deficiencies in the NMAC system (5.1.5).

- Safeguards audit should follow financial audit trends which require an element of unpredictability in audit procedures from year to year, and obligates auditors (via a list of considerations) to understand the business rationale for unusual transactions (5.1.2).

Any objective assessment of quality must be based on evidence, “keeping the score”.

- There should be metrics for performance that at least allow the auditors to verify the ability of the operator’s NMAC system to comply with 302/2005 and that this system is effectively implemented. Simple comparison with ISO standards and the NMAC guidance documents should be used as a metric on the general installation compliance framework, process capability and process maturity (5.2.1).
- The burden of metrics should in the first instance lie with the Commission and these should, as a priority, focus on those areas which may encourage the required performance improvements. Where deficiencies are found then operator’s good practice would be to provide progress metrics (5.2.2).
- Where operators offer access to an installation’s own performance monitoring system then those indicators should be taken into consideration and randomly checked for reliability and authenticity (5.2.3).
- Benchmarking against other installations will, for some installation types, be difficult to retain anonymity (for example reprocessing plants). For common installation types (e.g. reactors) benchmarking should be able to provide anonymity. The Commission should not discuss or disclose details of the audit findings with third parties without operator presence/approval. This includes utilisation of results for benchmarking purposes (5.3.4).

4. ESARDA support

ESARDA should continue to provide a forum where NMAC and safeguards audit can be elaborated and developed, audit experience exchanged, requirements harmonised, the guidelines enhanced and maintained as live documents. ESARDA could also support workshops, training initiatives and education programmes for safeguards audit awareness and reflect on linkages to other safeguards education initiatives.

The missing link in this audit work has been to establish the role of audit (if any) in the partnership

approach and integrated safeguards arrangements with the IAEA. The audit trials should be extended in order to determine the appropriate modalities in NNWS. Finland participated in some of the NMACAF meetings and offered to host such a trial. The ESARDA integrated safeguards working group should continue this work into how audit results could contribute to IAEA’s Integrated Safeguards approach, e.g. considered in the SLA (as confidence building measure).

The working group has explored the audit topic and the advisory report is also a reference work. It was apparent when compiling the report that the Commission should investigate further the real synergies and common tool set and decision processes with the quality and financial arenas. Such tools, often used by the operator, potentially provide better audit efficiency. ESARDA provides continued access to such operational experience.

5. Conclusion

Auditing should have a place within the framework of the Commission’s inspection role under the Treaty. It will provide more insight into an operator’s systems and a more holistic way of assessing the NMAC and safeguards procedural framework and quality control mechanisms. Audit methodology can also identify the information appropriate for facilitating the evolution of safeguards approaches.

In order to make progress on the deployment of audit it is first necessary to suitably define what the Commission means and intends by audit. Annex 5 of the advisory report clearly shows that major nuclear players, even after discussion in the working group, are confused as to what is meant by safeguards audit and the Commission must, as a priority create a clear dossier of common understanding of the safeguards audit approach and terminology.

How far and how fast the Commission goes down the audit path will depend on

- the results from the field trials and on the technical and cost effectiveness of audit.
- the determination of Commission and member states to develop the audit regime.
- the acceptance of audit measures by the IAEA, the member states and the operators.

The impact of audit on the Euratom safeguards regime is hard to quantify as it will depend on the qualitative factors such transparency, openness and unpredictability. Audit is however, not a substitute

for physical verification. This must be maintained at a level which provides credible safeguards assurance of non diversion.

Finally, many thanks should be extended to the participants in the working group and editorial teams who gave considerable time and energy to the task. Thanks also to the JRC in facilitating many of the meetings in their premises including the organisation and administration of the intensive workshop at Ispra. Finally thanks to ENUSA and the Spanish authorities who hosted the large combined NMACAF and IS working group meeting in Salamanca.

NMACAF Advisory Report - extracted suggestions

3.1 Systems audit in a Safeguards context.

3.1.1 The Commission should use large scope audits sparingly and only where interactions are complex or performance warrants it or there is significant change or organisational turbulence. The most appropriate systems audits would be themed, focussing on a particular aspect of NMAC throughout an installation.

3.1.2 The Commission should consider deploying the following levels of audit:

Scope: - Wide Depth: - Limited	Builds confidence that system quality and performance is being actively managed, a high-level compliance is present and that there are mechanisms to ensure promulgation of the management system. Can take significant account of the results of other audits and of accreditation, which has sampled the NMAC processes.
Scope: - Themed Depth: - Probing	Beneficial for process improvement of a major component that is exhibiting problems or which consumes considerable resources. Depth will depend on the importance of the component or the risk and may involve a large team. Themed audits should precede any review and reduction in inspection effort directed at that theme.
Scope: - Narrow Depth: - Narrow	Deployed on a planned and routine basis (suited to routine inspections) to gradually build a process capability view within existing resources.
Scope: - Narrow Depth: - Deep	This would respond to a very specific and significant problem area.

3.2 Justification for using systems audit.

3.2.1 The Commission should implicitly accept an assurance that an NMAC system is adequate where an installation has had extensive BTC verification, has been subject to routine inspection and has had

no significant or persistent performance issues. In these circumstances audit is not justified but could be accepted voluntarily as part of continuous improvement by the operator.

3.2.2 The Commission should explicitly determine if an NMAC system is adequate for installations that have no significant Euratom inspection history or have significant and persistent performance issues. The breadth and depth of such audit should be determined by risk assessment and installation specifics.

3.3 The current legal framework and Commission mandate.

3.3.1 Commission legal service should be consulted to determine whether the Commission has the legal right to audit, as this is not explicitly stated in the current legal instruments. If so, then audit could be implemented with a code of practice (the guidelines for conduct of audit and for good practice NMAC) and in accordance with the principle of proportionality. Proportionality should be applied on a case by case basis. Installations with good performance and compliance should be able to reject audits if the burden (cost) is disproportionate to the benefit (a contribution to EU safeguards assurance). If the legal basis is very narrow then any audit activity outside of that scope can only be done on a voluntary basis and the findings in the extended scope would have no legal status.

3.3.2 The Commission should deal with performance and quality assessment within normal inspection level monitoring. When a substantive review is required then this should be conducted as part of a collaborative framework of peer review of the operator's system and to encourage continuous improvement. In this context, the operator will own any improvements and therefore hold full responsibility to fully evaluate and risk assess any actions before accepting and implementing them.

3.3.3 Where performance issues are protracted or systemic, then the Commission, as part of due process, should offer the option to allow a full system audit before assessing whether to proceed to any

sanction action, thus taking an educational rather than punitive approach to enforcement where possible.

3.4 Audit methodology as a safeguards tool.

3.4.1 ESARDA should encourage European operators and member States to aid the Commission in defining the appropriate scope for audit inspections, failure to do so will ratchet the safeguards burden. Operators should however be encouraged to go beyond these confines, on a voluntary basis, in order to show active quality management and share performance metrics and internal audit findings. ESARDA should also encourage operators and member States to involve the Commission in follow up corrective action, learning from experience, preventative actions, measuring improvement and the operator's own deployment of PDCA process management.

3.4.2 Audits should not be conducted, even initially, on an informal basis. Whenever the Commission deploys systems audit or uses audit methodology it should provide proper advance notice.

3.4.3 All audit findings should be evaluated and presented in an audit report even where these arise from using audit methodology during routine inspections. This gives the proper reference environment and consolidates all audit activities. Audit can, nevertheless, employ a small random unannounced element especially in relation to in field verification and where the objective is detection.

3.4.4 All safeguards verifications using audit methodology should be conducted in line with the ESARDA guideline on conduct of safeguards audits.

3.4.5 The Commission should deploy fully qualified lead assessors when conducting systems audit. The Commission should ensure that audit methodology is only conducted by inspectors who have been assessed as suitably qualified and experienced personnel with the appropriate interpersonal skills. (process review using audit methodology does not require qualified lead assessors).

3.4.6 The Commission should be transparent about its audit activities and findings and the effect on personnel days on inspection (PDIs) whilst maintaining confidentiality about the installations concerned. The degree to which installations have volunteered for audit, beyond the scope of the legal requirements, should also be made clear.

3.4.7 The Commission should map process capability based on reality and not on documentation

and check that employees know what procedures 'affect' them and what controls are in place to ensure that procedures are followed.

3.4.8 The Commission should construct an annual audit plan for system and process audits. The mix (integration) between audit and physical verification should be based on an annual assessment and conveyed in advance to the operators in the audit plans. Commission audit planning should take into account any audit schedule provided by the operator and the operator should be encouraged to supply these at the same time as the annual programme of activities.

3.5 Impact of systems audit on the operator's NMAC systems and on key stakeholders.

3.5.1 A high standard of NMAC measurements is only necessary in bulk handling installations, where high measurement accuracy contributes to achieve acceptable MUF and SRD (prime indicators of NMAC performance). The Commission should be pragmatic about compliant measurement attainment in old bulk handling plants with high radiation backgrounds and extensive shielding. ("The system of measurements on which the records are based shall comply with the most recent international standards or shall be equivalent in quality to those standards").

3.5.2 Implementation of audit inspections will include a net additional cost and burden. The expected costs and benefits depend on the scope of these activities and the type of installation. The Commission should ensure that auditing is proportional, consistent and targeted in order to minimise costs and maximise benefit.

3.5.3 Operator's accountancy systems in bulk installations cannot be expected to detect the removal of a small quantity of material or provide a fast enough response to be useful in helping prevent theft or diversion. Timely detection of loss or diversion can however be assisted by C/S and/or by the inaccessibility of material.

3.5.4 The Commission should seek to minimise the burden of audits and by only requesting senior management involvement where there are significant performance issues or audit findings warrant it. Audit frequency should be minimised by ensuring targeted scope; by mapping processes rather than pressing for conformity to a conceptual model; by not insisting that installations must be managed and organised in a prescriptive fashion; and by proper

forward planning so that an operator can absorb the demand on time within normal resources.

3.5.5 The Commission should have (as in the regulation) special arrangements to deal with installations with small holdings and minimal procedural systems, provided performance and compliance is high, based on the competence of the individuals involved. In these cases, it is sufficient to ascertain that controls, contingencies and basic knowledge sets are in place to overcome the vulnerability of reliance on people and not on systems.

3.5.6 Systems audits should be conducted in the same way irrespective of the strategic nature of the materials since they focus on processes from a system and people perspective and ensure compliance and conformity. Performance control and credibility control must be heightened and focused in line with the risk of proliferation sensitivity of the material and its form (e.g. separated plutonium and HEU). Performance control must include all safeguards in depth features and not just NMAC.

3.5.7 The Commission should give a positive endorsement in their audit findings when appropriate and should give credit to operator's investments, achievements and accreditations. Such endorsement does not prove that there have been or can not be NMCA mistakes, it should simply state that adequate quality control exists on the NMCA process to ensure compliance of the product to requirements. (In QA parlance by proving and controlling the process you prove and control the product).

4.1 Relevance of other (ISO) quality and audit frameworks.

4.1.1 Given an increasing importance of quality matters in the EC safeguard approaches, it is important to avoid confusion over terminology. ESARDA should take steps to harmonise the vocabulary used for safeguards audits with that used by the general quality community.

4.1.2 When applying audit methodologies to nuclear material handling installations an appropriate reference must be used. Presently, no ISO standard is completely congruent with the requirements of Regulation 302/2005. ISO standards can be useful when some detailing or clarification of requirements of 302/2005 is necessary.

4.1.3 There are ISO standards (ISO 17025 and 100012) which relate to measurement systems and specific aspects of measurement (ISO 5725, 5479 etc). These together with international target values

should be the basis for making a qualitative assessment of the NMAC measurement system and uncertainties.

4.1.4 Audits of operators being certified to a management system standard, or whose measurement facilities are accredited to a technical competence related standard, may be facilitated if these management systems cover also the NMAC system of the plant (or parts thereof).

4.1.5 The Commission should, after building up audit experience, evaluate if these audits achieved their objectives both on a single audit level and on a general level; and whether all participants perceived benefit. Based on the results of this evaluation further decisions should be taken on whether to continue or discontinue the audit approach and what added further value might be gained from development of a dedicated NMAC Standard.

4.2 Taking into account other audits and accreditation.

4.2.1 In the case where the operator can prove (via evidence) that his accounting system, as far as it is safeguards relevant, is reliably checked on a routine basis by audits/inspections of third parties and its qualification (ISO certified or accredited) is maintained, those audit results should be relied on and accepted by the safeguards inspectorates. Where the audit results are produced by plant-independent auditors then this should increase credibility and enhance acceptance by the Commission.

4.2.2 Financial audits are inappropriate sources for sharing audit reports and activities. There is however, considerable synergy with respect to good underlying accountancy principles and audit practices that target control and risk. The Commission should investigate further this synergy and tool set and the decision processes that determine the level of physical verification in financial audits [ref 15].

4.2.3 Quality audits are an appropriate source for sharing audit results and activities and can reduce the resources and competency burden for both sides. Safeguards improvements may also be progressed via the same system for quality corrective actions.

4.2.4 Safety audits are generally not an appropriate source for sharing audit results except for situations where safety considerations significantly impede the normal course of inspection, are connected with reportable events which involved significant nuclear

material, are narrowly themed on NMAC core processes (moves, stocks, measurements etc). In these circumstances, significant benefit could arise from at sharing the results of such audits.

4.2.5 WANO style audits are conducted in a confidential framework and are not a proper source for sharing but are a model for peer review in which ESARDA could be a major player. WANO review criteria and performance objectives are clearly defined and their synergies for use in safeguards audits should be explored by the Commission.

4.2.6 Quality plans, assurance programmes and internal peer reviews are suitable information sources which should be taken into account in the safeguards audit assessments and in general confidence building.

4.3 Interaction with National authority NMAC standards and audits.

4.3.1 The Commission should take appropriate steps to ensure that audit type inspections are conducted in an equitable way among the EU members.

4.3.2 The Commission should encourage the State authorities to take part in the Euratom safeguards audit inspections and follow up. The Commission should provide the State with copies of audit reports and consider joint pursuit of resolution of audit findings. In some cases, it may be more appropriate that the member State monitors the follow up and shares the results with the Commission.

4.3.3 The Commission should collaborate with national authorities to examine whether national NMAC regulations/standards could be used throughout all the Commission NMAC audits within the State, along with the ESARDA NMAC guideline. In collaboration with State authorities, the Commission must take into account requirements and restrictions introduced by national legislation.

4.3.4 The Commission should seek an appropriate secure protocol with member States and operators if it wishes to conduct remote desktop compliance audits. Large amounts of procedural information should only be held remotely for a limited period, properly secured during use and be returned to the operator or confirmed destroyed within a prescribed period. Operators are not required to provide such information in electronic form and when they do, the information should be reviewed on stand-alone computers.

4.3.5 State authorities may have a national quality assurance programme to which the Commission

can take note. The Commission should consider how it might endorse such a quality assurance programme. The Commission in its role at the centre of European safeguards should also have its own quality assurance programme for which the IAEA can take note.

4.4 Impact on PSP, BTC and special reports.

4.4.1 It would be good practice for operators to have a concise statement of the NMAC implementation model and how and where it overlaps with installation quality management processes. This may take the form of a link map, a matrix relating Commission requirements for example, with the installation's quality manual or NMAC processes within the installation's overall quality framework. This is preferable to expanding the regulation companion guideline for what is expected in the BTC for a description of the accountancy system. Operators should also consider self-assessment against the guideline for good practice NMAC.

4.4.2 The Commission should not modify PSP to accommodate audit requirements unless this is a specific request by the operator/member State. Where a member State makes such a request, consideration should be given to application to all installation PSPs in that member State. Such an amendment to PSP would make audit requirements legally binding on the installation whilst at the same time clearly limiting the scope of information and activities to be included in the Commission safeguards audits.

4.4.3 The Commission should indicate in its guidelines to the regulation that special reports may include requests for further information of an audit and quality nature where procedural or management defects are possible root causes of the incident.

4.5 An industry good practice NMAC guideline.

4.5.1 The Working group has developed a draft guideline for NMAC and this now requires, via the auspices of ESARDA a broader consultation to ensure consensus agreement. Installations will be free to choose whatever technical solution best fits their plants but should be encouraged towards harmonisation with key elements of the NMAC guidelines.

4.5.2 Each installation should be encouraged to harmonise NMAC system processes across its

operating and business units to reduce complexity, enhance technical integrity, increase transparency and better enable efficient audit.

4.5.3 Guidelines for measurement practice should not require state of art of measurement technology, but should explicitly take into account plant specific requirements and commercial aspects. By accommodating these plant specifics, it can be determined whether highly sophisticated measurement techniques are needed to achieve the required level of analytical accuracy.

4.5.4 Good practice in the sense of target values may be defined for measurement/analytical methods and possibly for specific NMAC in selected sections of individual plants.

4.5.5 ESARDA and the Commission should ensure that the guideline for best practice NMAC is a live document to be refined. Reviews need to take into account the work of the INMM WINS project and the IAEA nuclear material accountancy handbook. These should be in harmony and ultimately congruent.

4.6 Audit measures appropriate for the scale of nuclear operations.

4.6.1 Bulk handling processes are best suited to substantive NMAC audit. The majority of installations in the EU however handle only items and the Commission should then deploy an approach to concentrate on material control and the procedures for unusual/infrequent transactions and events.

4.6.2 The majority of EU installations are small and the Commission should deploy a limited approach for efficient audit. A limited approach could be to notify a State that a low percentage of small installations in that State will be selected for audit each year and notified in advance in an annual programme of safeguards audits in that State. Audit checklists could also be deployed on a secure web based system and used (especially for small and infrequently inspected installations) in the selection process.

4.6.3 For Fuel Assembly (not MOX) items at nuclear powerplants, good NMAC systems and management oversight should allow more random interim verification with the possibility of reducing physical inspection visits to core unload/reload points. Operator PIV inspections between reloads should only be required if NMAC performance/audit findings warrant it.

4.6.4 Post operational and decommissioned installations should not be audited; these should be

dealt with under normal BTC verification. At the end of a bulk handling plant's lifecycle, it would be appropriate to conduct a performance review and an audit of the new NMAC arrangements for decommissioning arising.

4.6.5 Where installations are part of a highly centralised organisation then more emphasis could be placed on audit of the common system than on inspection. Where installations are parts of highly decentralised organisations and are autonomous then more emphasis could be placed on inspection.

4.6.6 For simple manual systems the safeguards approach emphasis could be on material inspection and issues of competence and training whilst for complex automated systems the emphasis could be on access/change controls and data validation, data authenticity and automatic checks and balances between the systems components.

4.6.7 Since good practice can only be 'voluntary', then the Commission should accept and record the operator's rationale as to why a particular good practice should not apply in their particular circumstance.

4.6.8 It is to be explored whether the NMAC guidelines can be laid out in a pattern tailored to specific plant types (as in the BTC). The most important aspect of readability is that bulk, item and small installations can see which guidelines are applicable. Special annexes should be created if specific fuel cycle or nuclear activity warrants it (e.g. research installations). In anticipation of new reactor build the NMAC guidelines have an annex for NPPs.

4.6.9 A high potential for improvement may be achieved by partially moving from classical inspections of products or status to system verification and evaluation as described. It is both unnecessary and mistaken to replace the term "inspection" by "audit".

4.6.10 The results of the presently performed field trials should be evaluated first and used for the definition of future audit measures. For the effective and efficient conduct of audits profound knowledge of the plant under consideration and its operation is indispensable.

5.1 Tools for assessing the NMAC and safeguards systems.

5.1.1 The Commission should draw on quality audit tools and techniques. These include general tools such as interviewing, observation, check

sheets, process mapping and the basic quality control charting tools and management diagrams. This will help to standardise the information collected. Such tools used by the operator will also provide a useful reference point for audits and could provide significant audit efficiency savings.

5.1.2 The Commission should also draw on the financial audit approach with respect to; a risk (of misstatement) based approach; assessment of the overall control environment; evaluating the effectiveness of internal controls and in depth investigation of unexpected/unusual movements. Safeguards audit should follow the financial audit trends which now require incorporation of an element of unpredictability into audit procedures from year to year, and obligates auditors (via a list of considerations) to understand the business rationale for unusual transactions. Of course, the prerequisite for this is that the auditor understands the installation and its management environment sufficient to recognise an unusual transaction.

5.1.3 The working group NMAC guideline should be used as an appropriate tool for considering NMAC quality issues during safeguards audits.

5.1.4 Design review tools and DIV tools are the basis for ensuring appropriate NMAC and safeguards provision in new plants but an audit is considered appropriate and necessary prior to a plant going activity. This is the most opportune and least costly time for NMAC systems to take onboard the guidelines for good practice NMAC.

5.1.5 Complementary safeguards tools (such as C/S, process monitoring and other features providing safeguards in depth) should also be included in the audit evaluation of performance as these often compensate for unavoidable or inherent deficiencies in the NMAC system.

5.2 Metrics for assessing NMAC performance.

5.2.1 There should be metrics for performance that at least allow the auditors to verify the ability of the operator's NMAC system to comply with 302/2005 and that this system is effectively implemented. Simple comparison with ISO standards and the NMAC guidance documents should be used as a metric on the general installation compliance framework, process capability and process maturity.

5.2.2 The burden of metrics should in the first instance lie with the Commission and these should, as a priority, focus on those areas which may

encourage the required performance improvements. Where deficiencies are found then operator's good practice would be to provide progress metrics.

5.2.3 Where operators offer access to an installation's own performance monitoring system then those indicators should be taken into consideration and randomly checked for reliability and authenticity. Guidance documents may constitute a reference for the implementation of the operator's NMAC system and assist in finding metrics for benchmarking.

5.2.4 Providing the anonymity of installations is maintained and there is non-disclosure of detailed performance issues then the Commission would increase transparency and public confidence by make an annual statement about quality across the EU NMAC systems.

5.3 Utilising the results of audits and potential for benchmarking.

5.3.1 In case benchmarking is foreseen then a very careful preparation and harmonisation must take place leading to mutual agreement between the Commission and the operators (ESARDA could provide a forum to help set up and harmonise the scoring system). Auditors involved in benchmarking must have excellent training on the scoring system in order to avoid/minimise bias.

5.3.2 The Commission needs to establish with each operator equitable target benchmark values for accuracy, timeliness, detection capability (quantity, detection probability, detection time) appropriate to the installation and material type. The Commission should not seek to impose performance levels for which the NMAC system was not designed.

5.3.3 The Commission should benchmark against the NMAC guideline and benchmark an installation across its own operations and its performance history. Indeed such benchmarking (keeping the score) is necessary if performance drives inspection activities.

5.3.4 Benchmarking against other installations will, for some installation types, be difficult to retain anonymity (for example reprocessing plants). For common installation types (e.g. reactors) benchmarking should be able to provide anonymity. The Commission should not discuss or disclose details of the audit findings with third parties without operator presence/approval. This includes utilisation of results for benchmarking purposes

5.3.5 It would be useful if the Commission could devise a clear methodology of rating and assigning a confidence level to an NMAC system.

6.1 Frequency and conduct of audits.

6.1.1 Audits, consisting of more comprehensive measures than carried out in physical verification should be an additional tool for the evaluation of irregularities or inconsistencies.

6.1.2 A Commission assessment programme should form the basis for the frequency and type of audits. An internal weighting system should be used to assign appropriate audits and this should be available to and the operator and its associated evidence. Audit scheduling must factor in other audit demands and workload peaks on the operator in order to minimise the burden.

6.1.3 Highly performing installations should have limited audit. A greater weighting could be given to the results of other audits (State, operator or third party) to limit safeguards audits to a very low frequency and to underpin a positive statement of compliance with the regulation.

6.1.4 The Commission's stated ambition for assessment at least every 24 months is not feasible if this translates to audit of every installation in that period. The within 24 month assessment should be considered as an assessment which may include an audit. In the case of the large numbers of small installations even a 24 month assessment may be replaced by randomised assessments and reactive assessments.

6.1.5 Significant events are best dealt with in the first instance using the special reporting requirements. Audit can then proceed without disrupting investigations and can focus on root cause identification and the appropriateness and completeness of corrective actions.

6.2 The Commission's competency requirements.

6.2.1 The audit team must be able to draw on a variety of behavioural and technical competencies but as a minimum, it should include one person technically competent and experienced with that type of installation and one person technically competent with audit skills.

6.2.2 As quality is closely tied with continuous improvement and not simply regulatory compliance, the Commission auditors should approach audits in a spirit of collaboration and employ a different

cultural approach to that used for physical inspections.

6.2.3 The legal framework does not require specific competencies for inspections or audits but the Commission should tabulate the appropriate behavioural and technical competencies for audit team members and ensure that audit team membership can cover the competencies identified as appropriate for particular activities or installations.

6.3 Managing the language barrier.

6.3.1 At least one member of the inspection team should have a good working knowledge of the local language. In the framework of "gentleman agreements", member States may provide assistance and some installations might volunteer to conduct audits in another language.

6.3.2 Written procedures could be translated and assessed before being further clarified in-situ, provided the operator sends them to the Commission in advance. In this framework, the use of Commission translation resources would be of advantage.

6.3.3 Consistent and high quality use of NMAC and audit terminology should be supported by a terminology database.

6.3.4 The Commission should keep a watching brief on R&D on machine translation developments should the language issue become a significant cost associated with audits.

6.4 Success criteria.

6.4.1 The Commission should seek to ascertain proof that quality is being managed with particular emphasis on internal NMAC controls and on response systems. This should not require a comprehensive ISO style audit of the installation quality management system.

6.4.2 Be clear that adequacy of the NMAC system beyond that in the Euratom regulation will be judged against the ESARDA guideline on NMAC and that divergence from that guideline will solicit comment and not compliance actions.

6.4.3 The Commission should formalise the process for marrying inspections and audit findings, and for deriving a confidence level (objective criteria) above that the Commission could look at reducing inspection activities towards a (pre-) defined minimum credible level. Audit follow up should be conducted, where feasible, within normal inspection visits.

6.4.4 The Commission safeguards audit modalities should be made transparent to all member States and operators. The audit trials should be extended in order to determine the appropriate modalities in NNWS (Finland has offered to host such a trial). The modalities should have a scope and frequency which adds value (assesses something new).

6.4.5 Successful audits need proper feedback loops and management review. The Commission should seek to evaluate audits (a) on a single audit basis—“what was learnt from this audit?”; (b) on a per installation basis—“was the recent series of audits useful for the installation’s improvement process?” and “did it change the Commission’s perception of this installation?”; (c) on a European basis:—“has NMAC quality increased in Europe as a result of the new approach?”.

6.5 Support to the operators

6.5.1 ESARDA to continue to provide a forum where NMAC and safeguards audit can be elaborated and developed, audit experience exchanged, requirements harmonised, the guidelines enhanced and maintained as live documents and to establish the role of audit (if any) in the partnership approach and integrated safeguards arrangements with the IAEA.

6.5.2 ESARDA could also support workshops, training initiatives and education programmes for safeguards audit awareness and reflect on links to other safeguards education initiatives.

6.5.3 The most significant support to operators is likely to be required for the first audit at an installation. In this respect support from the national authority and from the local audit community is paramount and the Commission should not seek an over ambitious scope.

7.1 Impact on inspection objectives, detection capability and physical verification.

7.1.1 The working group concluded that audits as an additional tool could increase safeguard credibility due to better-targeted inspections. Higher safeguards credibility can result from higher inspection specificity and higher inspection impact.

7.1.2 The Commission should state clearly if audit type inspections are only an added tool to the physical verifications or a complementary tool. In the second case, the number of physical verifications is related to a level of confidence granted to the operator.

7.1.3 Specific reductions in inspection activity because of audit were not readily apparent to the working group, especially in the integrated safeguards arena. Audit trial findings should be utilised to underpin any decision making and must be extended to gauge the impact on, and potential inclusion in, integrated safeguards.

7.1.4 On a short and medium term basis, the Commission should guarantee the credibility of its nuclear safeguards assurances by not using audit findings to significantly reduce inspection frequencies. Audit trials and experience, in addition to well formulated criteria for assessing confidence and risk, need to be in place and transparent to operators and member States before significant changes to the inspection mix take place. The Commission should set itself a time limit to gather such information and formulate its methodologies (ESARDA could assist in this task).

7.2 Impact on the IAEA and on Integrated Safeguards (IS).

7.2.1 The aim of both approaches is to strengthen the effectiveness and efficiency of safeguards. The principle procedure in both cases is to broaden the scope of aspects to take into consideration though the IAEA’s activities are targeted at the State while the Commission’s target is the operator. The safeguards agreements require that the IAEA shall make full use of the finding of the Commission’s safeguards system.

7.2.2 The ESARDA integrated safeguards working group should investigate how audit results could contribute to IAEA’s Integrated Safeguards approach, e.g. considered in the SLA (as confidence building measure).

7.2.3 To convince the IAEA of the usefulness of the application of audit methodology, the Commission should inform the IAEA on audit activities and results, discuss the results with IAEA inspectors to demonstrate the contribution audit methodology may have to improve safeguards effectiveness and efficiency.

Peer reviewed section

Stable noble gas isotopes for strengthening nuclear safeguards

The measurement point of view

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Abstract:

The IAEA is currently investigating new technologies to strengthen the effectiveness of its inspection and verification activities. In particular, the IAEA is looking for new methods and instruments, applicable to the detection of undeclared nuclear activities and facilities. Noble gases are produced during nuclear fission and are commonly released during reprocessing of the nuclear fuel. Recently, the IAEA Department of Safeguards held a Co-ordinated Expert Meeting on Noble Gas Monitoring at IAEA Headquarters in Vienna, to review the applicability of noble gas sampling, analysis and monitoring for IAEA safeguards. A feasibility study was performed at the EC-JRC-Institute for Reference Materials and Measurements (IRMM) in cooperation with the EC-JRC-Institute for Transuranium Elements (ITU.) This study investigated the potential to identify reprocessing activities by means of isotopic measurements of xenon and krypton. The KORIGEN code and the SCALE program were used to calculate the nuclear inventory of spent fuel for two scenarios involving high burn-up fuel, as well as for two scenarios that could be used for production of weapons-grade plutonium (low burn-up).

Noble gases produced during nuclear fission have significantly different isotopic compositions from those of natural noble gases. Consequently, major changes in isotopic composition result from dilution of the released noble gases with those from the atmosphere. This dilution process was “simulated” for noble gas generation due to high and low burn-up reactor operating scenarios by examining the isotopic alteration of xenon at different blending ratios.

The potential and limitations from the analytical measurement point of view, considering routine and reference measurements, to measure these changes in stable xenon and krypton isotopic ratios were

discussed. A potential laboratory network approach yielding reasonable cost-benefit quality assurance was suggested. The conclusion was reached that characteristic xenon and krypton signatures originating from irradiated fuel are a promising additional tool for verification of operators’ declarations of fuel reprocessed at large nuclear reprocessing plants. Within some constraints, the accumulated information gained from xenon signatures could also provide valuable information for nuclear safeguards detection of undeclared reprocessing activities, supplementary to radiometric measurements of ^{85}Kr .

Keywords: Noble gas signatures; isotope ratio measurements; nuclear safeguards; quality control

1. Introduction

Recently, concerns over changes in the nuclear programmes of some countries that have signed the additional protocol and/or the INFCIRC 66 type safeguards agreement have become of major public interest. The media and the press reported on IAEA negotiations with political leaders and on scientific expert opinions. Once more, the question of the purpose of nuclear weapons in the nuclear weapon states and the commitment of the non nuclear weapon states to never assemble such weapons of mass destruction were in the centre of public attention. The IAEA, in its role to safeguard nuclear materials and activities for peaceful purposes, faces technical and political challenges to ensure that there is no diversion to military use. To this end, the IAEA is currently investigating new technologies to strengthen the effectiveness of its inspection and verification activities. In particular, the IAEA is looking for new methods and instruments, applicable to the detection of undeclared nuclear activities and facilities. Noble gas monitoring has already been proposed in the past for the detection of undeclared reprocessing

activities. However, technology available at the time was insufficiently sensitive to detect the characteristic signatures of fission noble gases released during reprocessing and could not meet the IAEA's needs. Improvement in analytical techniques over the last 10 years encouraged the IAEA to look again into the matter of noble gas monitoring as a safeguards tool. Therefore, in 2005, the IAEA organised a technical meeting to review the applicability of noble gas sampling, analysis and monitoring for IAEA safeguards. The meeting participants discussed the applicability of noble gas monitoring, sampling and analysis for strengthening the IAEA safeguards in view of two basic objectives; for short-range detection of noble gases, to detect undeclared activities within the vicinity of declared facilities and long range detection of undeclared activities. For short-range detection, the isotopic signature of released fission off noble gases, particularly of stable isotopes, was identified to be one major point of interest. The European Commission Joint Research Centre Institute of Reference Materials and Measurements (EC-JRC-IRMM) was invited to this technical meeting due to its well-known expertise in the field of gas isotope ratio measurements. A feasibility study on the potential application of stable isotope ratio monitoring of noble gases was carried out in cooperation with the EC-JRC-Institute for Transuranium Elements (EC-JRC-ITU), to provide recommendations to the IAEA for the potential application of stable noble gas monitoring

2. Production of stable noble gases

Stable xenon and krypton isotopes are produced during fission in the core of a reactor. They are either generated as direct fission fragments or as daughter nuclei of beta-disintegration. Therefore, they show a greater abundance of heavier isotopes, compared to atmospheric xenon and krypton, coming from the neutron excess of the initial fissionable nucleus. In addition, the cumulative fission yields of the light isotopes are suppressed by the shielding in fission product beta-decay chains by very long lived precursors such as ^{129}I (107 yr half life). Noble gases are released during dissolution of the fuel batch and have a characteristic isotope signature depending on the history of the fuel being reprocessed.

3. Objective for stable noble gas application

At the technical meeting, the IAEA expressed the need for short range capabilities to detect undeclared production and reprocessing of one Significant Quantity (8 kg) of weapons grade ^{239}Pu in one year by a typical burn-up of 1000 MWd/MTU. To make a feasibility study on the potential to detect the

production of 1SQ Pu by means of stable noble gas measurements, probable proliferation sub-cases on reprocessing of the fuel were identified.

3.1. Proliferation sub-cases

For the first reprocessing sub-case, the dissolution of a large batch was considered over a year. The second sub-case assumed a proliferation scenario of weekly dissolutions. The case of daily dissolutions of small amounts of the fuel batch was considered as one of the most realistic scenarios for clandestine Pu production. Daily dissolution would admittedly bear the risk for a proliferator of releasing characteristic signatures for environmental sampling on a daily basis, but those signatures would be less significant with smaller alterations in the isotopic composition and thus more challenging to be detected by IAEA safeguards. Furthermore, for all the 3 sub-cases, a dilution factor in the reprocessing plant's stack of $10^5 \text{ m}^3/\text{h}$ was considered to be representative.

4. Feasibility study

A feasibility study was carried out to investigate whether the isotopic alterations in Xe and Kr collected in stack would be, from a mass spectrometry point of view, still measurable one hour after release. The KORIGEN code and the SCALE programme were used to calculate the fissiogenic noble gas inventories for 4 different reactor operating scenarios: 2 for electricity generation of 2 different reactor types and 2 for clandestine Pu production in the same reactors. The scenarios were the following:

- Scenario A: PWR, UOX 3.5 % ^{235}U enrichment, high burn-up
- Scenario B: PWR, UOX 3.5 % ^{235}U enrichment, low burn-up
- Scenario C: CANDU, natural U, high burn-up
- Scenario D: CANDU, natural U, low burn-up

There is a correlation of released noble gases to the magnitude of Pu production of a specific reactor operating scenario. The low-burn up scenarios account for the production of weapons grade Pu of 98% enriched ^{239}Pu [1].

4.1. Fission to atmospheric noble gas ratio

Once released, stable Xe and Kr mix with atmospheric Xe and Kr. More xenon than krypton is present in the fission off gases. Since xenon is less abundant in air than krypton the feasibility study focused on the xenon fissiogenic inventory. Table 1 shows the parameters of the different scenarios and the amount of fission Xe produced due to the 3 proliferation sub-cases.

Table 1: Xenon fissiogenic inventory and fission to atmospheric noble gas ratio

	Scenario A			Scenario B		
Reactor type: Burn-up Fuel: Irradiation time: Cooling time:	UOX-PWR 33 GWd/MTU 1 GWd/MTU UOX-3.5 % ²³⁵ U enrichment 3 years 1 month 3 years 1 month					
air flow rate in stack:	10 ⁵ m ³ /h					
	10x / year ~per 100kgU	1x / week ~per 20kgU	1x / day ~per 3kgU	10x / year ~per 100kgU	1x / week ~per 20kgU	1x / day ~per 3kgU
Fission Xe in g:	541	108	16	21	4	1
Fission Xe: atm. Xe after 1h:	1 : 0.1	1 : 0.4	1 : 3	1 : 2	1 : 10	1 : 69
	Scenario C			Scenario D		
Reactor type: Burn-up Fuel: Irradiation time: Cooling time:	CANDU 9 GWd/MTU 750 MWd/MTU natural uranium 1 year 1 month 300 days 50 days					
air flow rate in stack:	10 ⁵ m ³ /h					
	10x / year ~per 100kgU	1x / week ~per 20kgU	1x / day ~per 3kgU	10x / year ~per 100kgU	1x / week ~per 20kgU	1x / day ~per 3kgU
Fission Xe in g:	154	31	5	12	2	0.4
Fission Xe: atm. Xe after 1h:	1 : 0.3	1 : 1.4	1 : 9	1 : 4	1 : 18	1 : 120

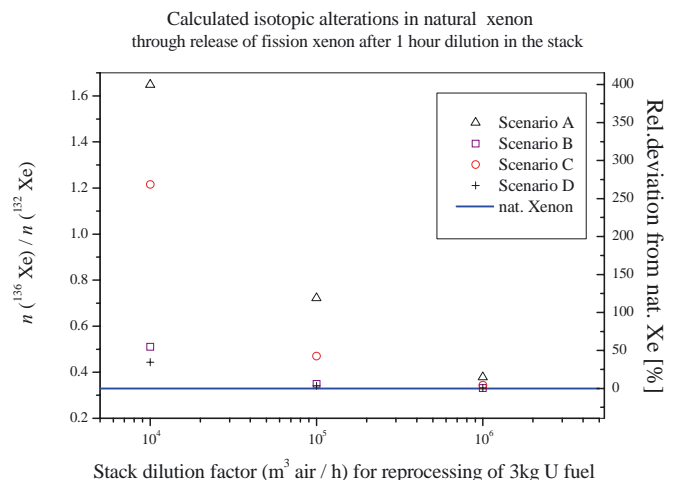
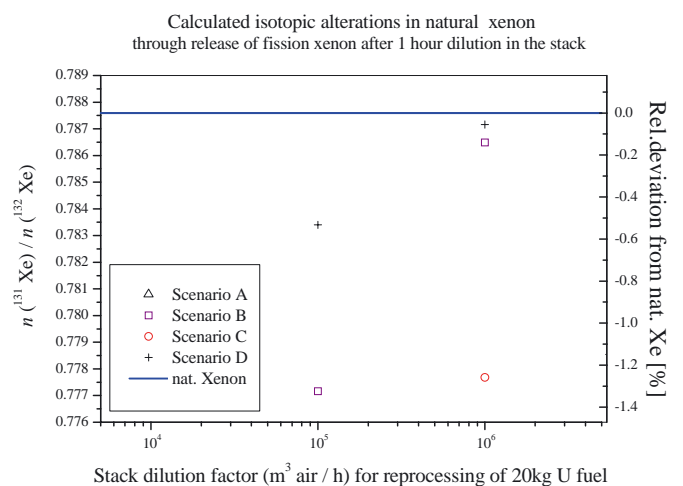
The expected fission to atmospheric noble gas ratio is quite high for the proliferation sub-case of 10 dissolutions per year compared to the daily proliferation sub-case.

4.2. Isotopic alterations

To obtain a reliable estimation of the expected changes in the isotopic composition of atmospheric xenon due to blending with released fission xenon, the “simulation of the dilution process” for scenario A, B, C and D was performed by examining the isotopic alteration of xenon at different blending ratios. These ratios correspond to an estimated air flow rate in the stack of 10⁴ m³/h, 10⁵ m³/h, 10⁶ m³/h and to the discussed proliferation subcases for undeclared reprocessing. Figure 1 shows the change in the $n(^{136}\text{Xe})/n(^{132}\text{Xe})$ for a daily reprocessing activity with increasing stack dilution factor compared to atmospheric xenon.

Figure 2 shows the change in the $n(^{131}\text{Xe})/n(^{132}\text{Xe})$ for a weekly reprocessing activity with increasing stack dilution factor compared to atmospheric xenon.

The deviation from the atmospheric isotope ratios is significant and differs for the high and low burn-up scenarios. By measuring these kinds of alterations in the blend and by measuring the isotopic composition of atmospheric xenon, conclusions can be drawn on the isotopic composition of the initially released noble gases by simply applying the

Figure 1: Isotopic alterations for a daily reprocessing activity**Figure 2: Isotopic alterations for a weekly reprocessing activity**

Isotope dilution equation with the constraint that the light isotopes are not produced via nuclear fission [2]. The calculated initial isotopic composition of the fission off gas at the dissolver could be used as input parameter for models that render probabilities on fuel parameters and reactor operation.

5. Mass Spectrometry

The isotopic measurement procedure at IRMM for high accuracy gas isotope ratio measurements is based on the controlled gas flow from the mass spectrometer inlet system to the ion source through a molecular flow gold leak. Therefore, the signal acquired at the detector depends exponentially on the gas partial pressure and the time. The observed ion currents are corrected for this mass discrimination and by means of gravimetrically prepared synthetic isotope mixtures for any residual errors [3, 4]. In order to measure small isotope ratios, recent improvements have been made to the hardware by introducing a combined Secondary Electron Multiplier (Ion counting) and Faraday detection. This allowed the measurement of isotope ratios lower than 10^{-7} opening a large field of investigation for natural isotope studies and highly enriched isotopic samples. This progress in mass spectrometry techniques increases the possibility to measure all the required mass-to-charge signals for the complete determination of the isotopic fractional abundance of noble gases.

5.1. Limit of detection

A set of ratios suitable to detect undeclared nuclear activities were identified as a result of this feasibility study. The limits of detection resulting from this feasibility study, assuming high accurate mass spectrometry techniques, are summarised as follows:

- $n(^{136}\text{Xe})/n(^{129}\text{Xe})$, $n(^{134}\text{Xe})/n(^{129}\text{Xe})$, $n(^{128}\text{Xe})/n(^{134}\text{Xe})$
 - Very suitable for detection of undeclared nuclear activity: Detection of alteration to a dilution factor in natural xenon of about 1:100 000; i.e. $2\text{--}3\cdot 10^8 \text{ m}^3$ air per emission of 1 g fission xenon
- $n(^{136}\text{Xe})/n(^{132}\text{Xe})$, $n(^{134}\text{Xe})/n(^{132}\text{Xe})$, $n(^{131}\text{Xe})/n(^{134}\text{Xe})$
 - Suitable for detection of undeclared nuclear activity: Detection of alteration to a dilution factor in natural xenon of about $2\text{--}3\cdot 10^3 \text{ m}^3$ air per emission of 1 g fission xenon

- Suitable for detection of undeclared nuclear activity within a declared facility: Distinction between scenarios to about $5\cdot 10^6 \text{--}2\cdot 10^7 \text{ m}^3$ air per emission of 1 g fission xenon
- The detection limit for high-accuracy measurements after 1 hour for isotopic alteration of $n(^{136}\text{Xe})/n(^{132}\text{Xe})$ due to proliferation reprocessing (low-burn-up) of 3kgU–100kgU corresponds to a stack dilution factor of $1\cdot 10^8\text{--}5\cdot 10^9 \text{ m}^3$ air / h
- $n(^{131}\text{Xe})/n(^{132}\text{Xe})$
 - Very suitable for detection of undeclared nuclear activity within a declared facility: Distinction between scenarios to about $5\cdot 10^7 \text{ m}^3$ air per emission of 1 g fission xenon

To be complete, detection limits for Kr are also given.

- $n(^{86}\text{Kr})/n(^{84}\text{Kr})$
 - The detection limit for high-accuracy measurements after 1 hour for isotopic alteration of $n(^{86}\text{Kr})/n(^{84}\text{Kr})$ due to proliferation reprocessing (low-burn-up) of 3kgU–100kgU corresponds to a stack dilution factor of $7\cdot 10^5\text{--}2\cdot 10^7 \text{ m}^3$ air/h.
 - Detection of alteration to a dilution factor in atmospheric krypton of about $3\cdot 10^7 \text{ m}^3$ air per emission of 1 g fission xenon. Distinction between low and high burn-up to about $3\cdot 10^5 \text{ m}^3$ air per emission of 1 g fission xenon

6. Potential of the stable noble gas monitoring

The relative measurement uncertainty on Xe and Kr isotope ratio measurements is 0.001% for high accuracy measurements and 0.1%–0.5% for routine measurements. The feasibility study has proven that all assumed proliferation sub-cases could definitely be detected from an analytical point of view for a stack dilution factor of 10^5 m^3 air / h, even by means of routine stable xenon isotope ratio measurements. Noble gas monitoring definitely has a potential to detect and identify undeclared activities. The detection of the change in xenon isotopic ratios from the natural abundance would be challenging but feasible in samples taken up to 1 hour after release in the case of access to the stack. It needs to be investigated whether existing stack monitoring systems could be used with slight modifications for noble gas sampling.

Besides this application, stable xenon and krypton measurements have a high potential for other

safeguards related applications. In particular, stack sampling and measurements of stable noble gases could also be used to confirm operators' declarations of reprocessing at large reprocessing plants.

7. Quality control (QC)

Reliability and comparability of analytical results on stable noble gases are an indispensable prerequisite for IAEA safeguards application. Analysis of noble gas samples could be done using a network of analytical laboratories, in a similar approach as for swipe sample analysis. There are already laboratories working in the geological and cosmological research field that have performed high quality measurements on stable noble gases successfully for years. For laboratory-based analyses, a network could be established from existing laboratories that fulfil the IAEA quality assurance requirements and are in alignment with ISO 9000 or ISO 17025. The laboratories would need to analyse a number of QC samples; to participate in recognised interlaboratory comparison schemes; and to use high-quality reference materials for their method evaluation. Once implemented, stable noble gas monitoring could be a cost-effective tool for nuclear safeguards purposes.

8. Conclusions

To strengthen the IAEA safeguards system for verification of the completeness and correctness of a State's declaration, all available characteristic signatures need to be taken into account. In the present study, the benefit of applying noble gas stable isotope measurements to supplement existing techniques has been demonstrated. In particular, such measurements enable information to be gathered on activities undertaken within declared reprocessing plants in a largely non-intrusive way i.e. through sampling at the off-gas stack. The conclusion was reached that characteristic xenon and krypton signatures originating from irradiated fuel are a promising additional tool for confirmation of operator declarations of fuel reprocessed at large nuclear reprocessing plants. Within some constraints, the accumulated information gained from xenon signatures could also provide valuable information for nuclear safeguards verification of undeclared reprocessing activities, supplementary to radiometric measurements of ^{85}Kr . The recommendation of the technical expert group summarised in the report to the IAEA, STR-351, was that more numerical simulations need to be performed with subsequent experimental verification and a cost-benefit study.

9. Acknowledgements

The authors very much acknowledge the support from Paolo Peerani (JRC-IPSC), who provided the fissiogenic inventory data for this feasibility study.

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Tribune and opinions

From silver to radium

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Jáchymov, once called Joachimsthal is a place in Czechia. Long ago, about 1512, Joachimsthal became one of the largest mining centres in Europe for silver. The minted silver coins from that place became famous by their name “Joachimsthalers” or “Thalers”. Today the word lives on in a corrupted form: “Dollar”. Around 1550 the silver deposits dwindled, and as they did, the miners encountered a mysterious black mineral whose presence indicated that more silver was unlikely. They called this ore “pechblende”, which in German means pitch (black) mineral. It was a pun since “pech” also means bad luck. Pechblende was also bad luck for another serious reason. The region’s miners suffered an unusually high number of fatal lung disorders, a probable mix of silicosis, tuberculosis, and lung cancer, but during old times in the mind of the people these mines were haunted by bad ghosts.

In 1789 M.H. Klaproth identified uranium oxide in the pitchblende ore. Uranium became vitally important to Bohemia’s ceramics and glass industry as a colouring agent. In the years about 1898 systematic investigations by Marya Curie Skłodowska and Pierre Curie led to the discovery of three other radioactive elements from pitchblende: polonium, radium, and actinium. Soon radium became quite popular for its strong radioactivity and the supposed beneficial health effects thereof. One gram of radium is contained in about 3,5 ton of uranium. As a result, radium rapidly surpassed uranium (and everything else for that matter) in value, costing more than one hundred thousand dollars per gram. Jáchymov became the world’s major source of radium and a famous health spa. Other less rich ores had been discovered as well,

e.g. between 1913 and 1916 in the US the mining company “the National Radium Institute” charged \$ 180 000 per gram of radium extracted from indigenous carnotite ore. This ore also contains the useful vanadium, which is used for production of high-strength steel.

Radium on the decline

Radium was considered to be beneficial for your health. Hence there was no hesitation for the girls that were painting radium on luminous dials to moisten their brushes with a bit saliva, by which those girls had ingested quite some radium. Even during their instruction period the teachers showed that radium was harmless by taking a bit. A vigilant dentist noted the affect of radium in the mouth of these girls. In 1926, the outcome of the “Radium Girls Lawsuit” in the USA, marked the beginning of the decline of the unlimited positive image of radium. Bad Luck again? Radium health spas, like the other spas suffered a decline which was enhanced by the great economic depression of 1929 and later from wartime. However, also the widespread belief in the good character of the natural sources of radioactivity persisted for long. The continuation of the many health spas using and distributing their radioactive products abroad illustrates this persistence. One of the most recent examples is the 1992 advertising of the health spa of Joachimsthal praising still its different health treatments with radioactive materials.

In the forties of the twentieth century the discovery of nuclear fission of uranium should result in a revival of the mining of pitchblende ore as part of the uranium rush.

Scientific papers (not peer reviewed)

The Role of SITMUF in NRTMA¹

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1. Abstract

A key performance indicator for nuclear processing plants is the Inventory Difference² (ID), also known as the Material Unaccounted For (MUF) over a campaign (year) and its objective analysis is key to tracking and correcting sources of measurement and accountancy anomalies. Ultimately the goal of such analysis is to have available a tool that can identify individual components of the ID so that plant effort can be focused and directed at appropriate corrective action.

This paper presents a brief overview of the principles behind measurement control and looks at the role of SITMUF³ in the system currently in use at Sellafield Ltd. on its Thorp reprocessing and SMP fabrication plants and discusses the reasons why it was chosen in preference to directly analysing ID and cumulative ID (CUMUF). In particular it highlights the problem of controlling False Alarm Probability (FAP) and the benefits of using the SITMUF approach when looking to identify anomalies.

2. Introduction

IDAL TEST

At the end of a given period, the Conventional Accountancy books can be closed, a Physical Inventory Take (PIT) carried out and any discrepancy, deemed an inventory difference (ID) noted. The calculation method is given by

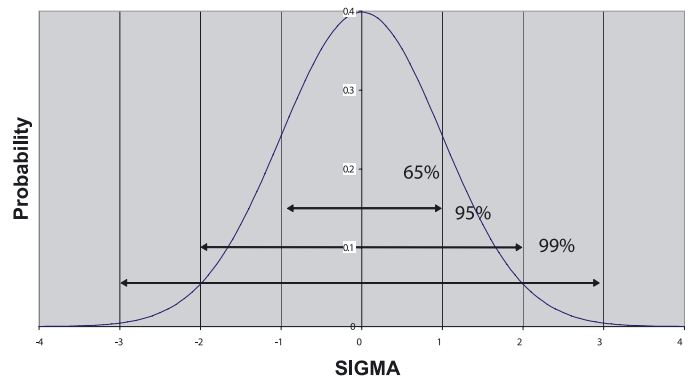
$$ID = PIT - BB = PIT - (OB + R - S)$$

ID – Inventory Difference
PIT – Physical Inventory Take
BB – Book Balance
OB – Opening Book Balance
R – Receipts
S – Shipments

The significance of the ID is usually determined by comparison against its uncertainty, σ_{ID} which is calculated by cumulating the individual uncertainties of the transactions and inventories that make up the Physical inventory and the Book Balance.

$$\sigma_{ID}^2 = \sigma_{PIT}^2 + \sigma_{BB}^2 = \sigma_{PIT}^2 + \sigma_{OB}^2 + \sigma_R^2 + \sigma_S^2$$

Distribution of ID



The ID is considered acceptable if it falls within a given number of standard deviations of the expected value (0). Such an approach also defines a false alarm probability (FAP). This is the probability that a period over which the accountancy has been carried out will end in an alarm simply through random fluctuations of measurement. For example, a choice of Alarm threshold of $\pm 2\sigma$ will give ~5% FAP. Expressed in a slightly different way this is a t-test⁴. We are looking at the ratio of ID/σ_{ID} . If this is greater than 2, for example, then we say that the system has alarmed. There are two important caveats to this test.

1. A t-test is not robust if the data is not normally distributed.
2. A t-test is seriously not robust if the data is correlated.

This test is always chosen at the end of a campaign. Whilst it may be the 'best' test available⁵, the issue with this test is that it is simply not that useful for diversion or anomaly detection. Whether the loss scenario is abrupt or protracted, the loss/gain cannot be discovered in a timely fashion.

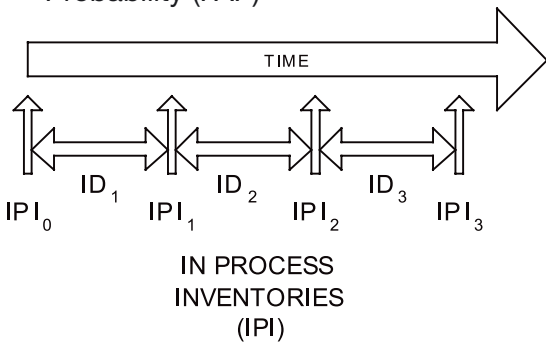
3. Multiple Tests

There is a requirement for timely detection⁶. In order to do so, some form of frequent test with an associated alarm level has to be designated. A first pass might be the repeated use of the IDAL test either on ID or CUMUF at regular intervals during the campaign. This was extensively researched

during the 70's and 80's⁷. Unfortunately such an approach faces a number of issues⁸.

There are two main problems that this type of technique would have to overcome:

1. At the very least the closing inventory of one period and the opening inventory of the subsequent period are shared. This leads to correlation between the tests and the inapplicability of the t-test type of approach. In practice the correlation is more complicated than this which leads to even more significant failure of the test strategy.
2. Because of the nature of Markov chains and random walks of which this is an example, all campaigns will end in alarm if the campaign goes on long enough. The objective is to find a test statistic where only 5% (say) of the runs finish in alarm within the length of the campaign. The requirement here is to control the False Alarm Probability (FAP)



$ID_1 \quad ID_2 \quad ID_3 \quad ID_4 \quad \dots ID \text{ sequence } \overline{ID}$

$$\begin{bmatrix} V_{11} & C_{12} & C_{13} & C_{14} & \dots \\ C_{21} & V_{22} & C_{23} & C_{24} & \dots \\ C_{31} & C_{32} & V_{33} & C_{34} & \dots \\ C_{41} & C_{42} & C_{43} & V_{44} & \dots \end{bmatrix} = [V]$$

Variance /Covariance Matrix

$$[T][V][T]^T = [U]$$

$$\rightarrow [T] \times \overline{ID} = \tilde{I}$$

The first problem is not so much a problem as a challenge to the understanding and modelling of the plant in question. If the operation of the plant is well defined then it should be possible to model into the assessment of ID and its associated variance the covariance terms required. In other words, this is not an issue of approach but of implementation and therefore applies equally to all methodologies.

The second problem is more subtle but much more difficult to deal with. In order to determine the FAP it is necessary to know the run length distribution which is itself a function of test statistic methodology

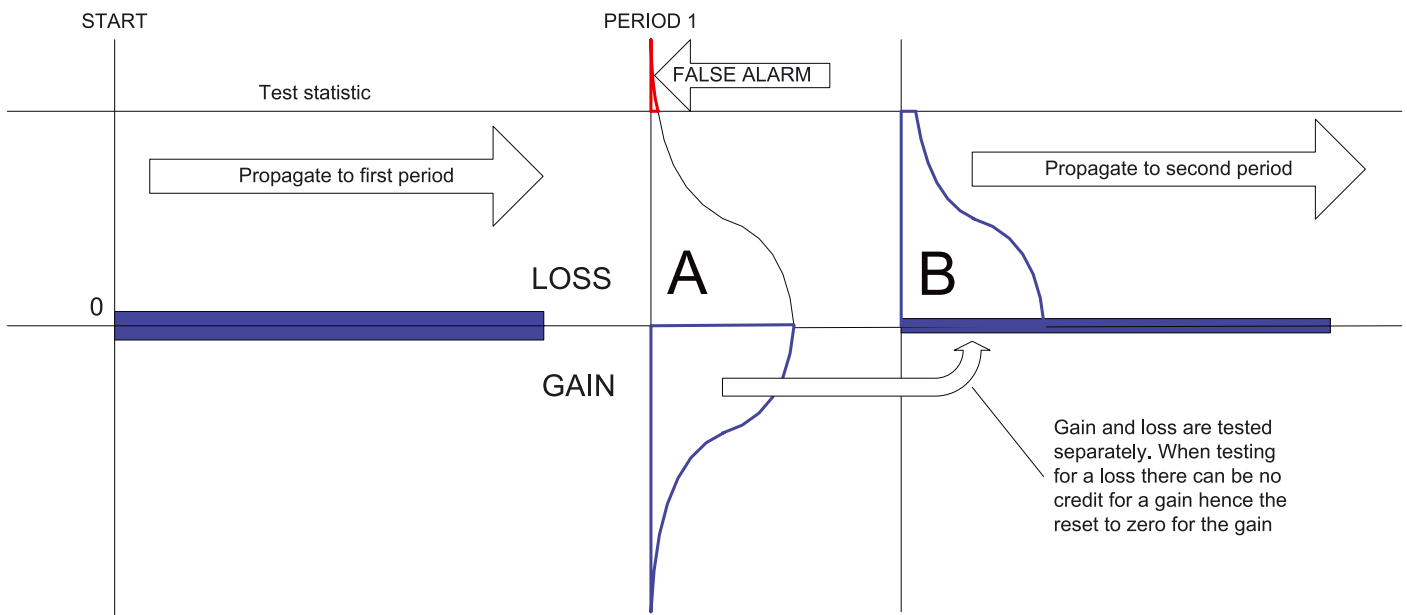
and the error structure of the campaign. Methodologies that use ID and CUMUF directly can only 'guesstimate' this because the true error structure is only known at the end of the campaign and therefore fails the timeliness criteria. The performance of all these methodologies is therefore limited by the quality of the estimate and no truly analytic method can exist for determining the FAP.

4. The Role of SITMUF

Fixing FAP for a Campaign

It is perhaps easiest to view the problem from the end backwards. The given statistic is the overall FAP which is predefined whereas what is required is the ability to test at each period. If the ID sequence comprised of independent terms then the problem becomes straightforward, viz for an abrupt loss, $(1 - FAP) = (1 - p)^n$ where n is the number of periods in a campaign and p is the required FAP per period. This independence is not hard to achieve. It is a basic principle that for a given sequence [ID] with variance/covariance matrix [V] there exists a sequence [I] with variance covariance matrix [U] as in the formulae and where [T] is an appropriately chosen lower triangular matrix. The matrix [U] is diagonal. This, in turn, implies that the elements in [I] are independent. This vector of terms, [I], is usually termed an ITMUF sequence. Now it is possible, given the period probability p , to determine a statistic for each period which will have a distribution from $N(0, \sigma_p^2)$. Much simpler is to calculate one statistic based on $N(0, 1)$ and normalise the ITMUF sequence using the diagonal matrix, [U], coefficients as the variance of each ITMUF term. This produces the SITMUF sequence of the title⁹.

For an abrupt loss the use of SITMUF is a convenience rather than a necessity. It makes sense to have one statistic for the campaign rather than one for each period. When it comes to determining the false alarm for a protracted loss then the problem becomes more complex. Consider the situation at the start. All possible outcomes for campaigns are zero with probability 1 because at the start nothing has happened. Activity starts and, assuming the plant is in control, the outcomes at period 1, for all campaigns, are given by a normal distribution $N(0, \sigma_p^2)$ (diagram A). Some campaigns will therefore cause a false alarm. For an abrupt loss everything resets to zero and the alarm probability is the same in every period which makes the calculation of the total FAP easy to manage. For a protracted loss the result is a truncated normal distribution (diagram B) which has to be propagated.



In order to propagate this it is necessary to know, at period 1, what the distribution at period 2 will be and similarly, to determine the FAP for the campaign, also the distribution at periods 3, 4...., to the end of the campaign. This is clearly not possible for tests based on ID, CUMUF and ITMUF. For these, the information only becomes available at each period and not in advance. For a SITEMUF sequence, however, every period is $N(0,1)$ by definition and therefore the propagation is possible. It simply has to be decided how many IPIs there will be in the campaign. In this way a statistic for the protracted loss can also be found.

Analysing Anomalies

In a no diversion/bias scenario then the SITEMUF sequence, S , should be simply noise from the measurement system, i.e. a random set of numbers drawn from the $\vec{\epsilon} \rightarrow N(0,1)$ distribution. In an alarm situation this sequence is perturbed by a loss (gain) vector, \vec{T} , representing the 'true' anomaly. This means that the observed vector, \vec{O} , can be considered as $\vec{O} = \vec{T} + \vec{\epsilon}$ and therefore $(\vec{O} - \vec{T})^2 = (\vec{\epsilon})^2$ which is a $\chi^2(n)$ distribution.

But what if the wrong model, \vec{M} , is picked? There will be a difference vector, $\vec{\delta}$, between the true vector and the model. This gives $(\vec{O} - \vec{M})^2 = (\vec{\epsilon} + \vec{\delta})^2$ which is a non-centered χ^2 distribution.

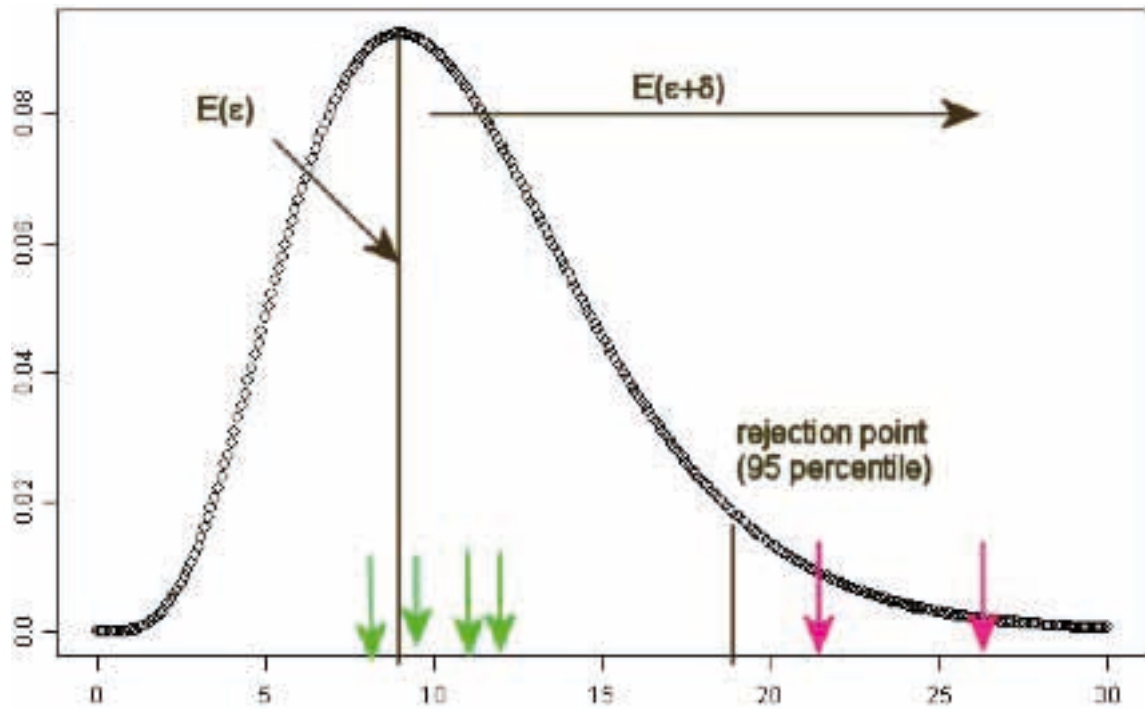
The version of NRTMA currently in use calculates an exhaustive list of models which are compared according to the χ^2 value generated. From the nature of χ^2 and non-centered χ^2 distributions we know that $E(\vec{\epsilon})^2 < E(\vec{\epsilon} + \vec{\delta})^2$ i.e. the expected value of the true model statistic/ will be less than the expected

value of the wrong models. The 'true' model statistic would be expected to be, if not at the top, within a specified limit (95%) of the number of degrees of freedom. This allows rejection of all potential models at some cut off point in the list and therefore simplifies the investigation process. The graph shows the distribution of for a ten period sequence. The expected value for the true model is the maximum of the graph. The expected value for all other models will lie to the right of this point. Any model whose value lies outside the 95 percentile (red arrows) is rejected. The green arrows represent possible acceptable models. Clearly the one with the lowest value is the favourite but the only real answer is to go to the plant and look. The objective here is to limit the scope of investigation and to give a point to start from.

In practice a more sophisticated approach is used which also takes into account additional factors such as composite models when winnowing the list of potential models. Again there is no equivalent analytic solution existing for methodologies based directly on ID or CUMUF.

5. Conclusion

For a small added complexity, i.e. transforming ID to independent form and normalising, the use of SITEMUF confers several advantages over the analysis of untransformed sequences, e.g. ID and CUMUF. The ability to produce a credible statistic for testing without either simulation, or estimation of campaign variance, is in itself significant. The additional advantage of being able to bring a degree of statistical rigour to the analysis of anomaly resolution results has made it the approach of choice for Sellafield Ltd..



6. References.

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- 7 Russell NS, A Review of NRTMA Statistical Tests, Safeguards R & D Project, SRDP-R114, 1984
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Endnotes

- 1 **Near Real Time Materials Accountancy**
- 2 Inventory Difference (ID) is defined by $ID = PIT - BB$ where PIT is the closing physical inventory and BB is the book balance calculated as $BB = \text{Opening Inventory} + \text{Receipts} - \text{Issues}$.
- 3 Standardised Independently Transformed Material Unaccounted For
- 4 A t-test is any of a number of tests base on the t distribution. The general formula for t is $t = \frac{\text{statistic} - \text{hypothesised value}}{\text{std. deviation}}$
- 5 Professor Avenhaus, in a short paper [ref. 6]; showed that no multiple test can be more powerful than a single test at the end of a campaign.
- 6 See IAEA Safeguards Criteria Annex A-7 TS No 9 01/3/1999
- 7 See reference 7 which provides a review of then current testing approaches.
- 8 A paper by Speed and Culpin (ref. 8) extensively reviewed many of the then new approaches.
- 9 A complete mathematical description of the transform and computational aspects of the process are given in ref. 9

Technical Sheets

A few words about Technical Sheets

from the ESARDA Secretary

In 2004 ESARDA decided to publish Technical Sheets on its website in the "Library" section. They were aiming at presenting in a few pages, the basics of principles, technologies or methods widely used in the safeguards and non proliferation fields.

Today twelve Technical Sheets are available, completed by one on Non Destructive Assay and two new ones on Containment and Surveillance, so a total of fifteen Technical Sheets.

Last year, in its issue n° 35 dated December 2005, the ESARDA Bulletin was inaugurating a section entirely devoted to Technical Sheets. Four of them were published and immediately posted on the website, then completing the list of those which were already available.

In the issue n° 36 no Technical Sheet was published, because many of them were in preparation.

The present issue releases all the six TS in the fields of Non Destructive Assay published since 2004. Three of them were posted in the website before the decision to publish them in the Bulletin was taken; two others were published in the issue n° 35 and are updated today for their second publication in this issue. The last one is on the *Photon Absorption / Excitation Techniques* that also includes the *K-edge densitometry*.

Therefore, all NDA TS are now available in the same Bulletin issue.

They are completed by two new TS on Containment and Surveillance: one on *Radiation Monitoring Techniques for Monitoring the Movement of Discharged Fuel*, the other on *ultrasonic seals developed at the Joint Research Centre*.

Most Technical Sheets are drafted by the ESARDA Working Groups; for that purpose, Working Groups

have modified their Terms of Reference and included drafting (and reviewing) TS as a routine activity. Some others are drafted by individuals, in the frame of their professional activities, often in addition to their normal duties.

In this way, they are actively participating in the diffusion of knowledge in the safeguards area.

It was indeed stated in December 2006, that

"the Technical Sheets are part of the didactic approach set up by ESARDA in the field of Nuclear Material Accountancy and Control.

This approach consists of presenting a gradual didactic material on the website:

- The **glossary** that defines in a few words concepts, equipment, methods etc.
- The **Technical Sheets** that describe in a few pages the techniques used, their physical principle and their application fields;
- The **ESARDA course** that gives young professionals or students in nuclear engineering, the basics for understanding and using the safeguards concepts and technologies."

One will find in the third cover page of the present issue the announcement for the next ESARDA course. No need to say that the three previous sessions have encountered a huge success: 18 students and young professionals in 2005 (first session given with the participation of ESARDA lecturers) 45 in 2006, 61 in 2007 !! In total, and taking into account the first 2005 session, more than 120 people have followed the training course.

A range of new TS are in preparation and will be published in the coming Bulletin issues.

Active Neutron Coincidence Counting Techniques for ^{235}U Mass Determination

1. Objective of the technique

Active Neutron Coincidence Counting (ANCC) is a technique for determining the mass of ^{235}U in uranium-bearing samples with any enrichment (from LEU to HEU) in most of the usual chemical and physical forms such as powder, metal, pellets, fuel elements, and waste drums.

2. Presentation of the technique

2.1. Principle of measurement / Definition of the physical principle

Due to the very low spontaneous fission yields of all the uranium isotopes, passive neutron coincidence techniques are generally not suitable for the assay of uranium bearing samples (an exception is the use of (α, n) reactions from ^{234}U in uranium fluoride or the use of spontaneous fission of ^{238}U in large size LEU oxide samples). However the fissile content in a sample can be readily measured by adding an external interrogation neutron source. The neutrons from the interrogation source will induce fission in the fissile nuclei of the sample. Neutron induced fission (like spontaneous fission) results in the simultaneous emission of several prompt neutrons ($\bar{\nu}=2.41$ for fission induced by thermal neutrons in ^{235}U). The coincidence counting technique allows the distinction between events with the emission of single or multiple prompt fission neutrons. This makes it possible to discriminate between neutrons from the primary interrogating source and those from fission induced in the sample, provided that the primary source generates randomly non-correlated single neutrons. Coincidence counters with a random interrogation source are known as Active Neutron Coincidence Counters.

Among the radioactive sources those based on (α, n) reactions are the best candidate for active neutron interrogation. A frequently used source is AmLi. The main advantage of the AmLi source with respect to other (α, n) reactions is the low energy of the emitted neutrons: the mean energy is 0.54 MeV, which minimises the probability of fast fission in ^{238}U .

For small samples the “true” coincidence rate is proportional to the quantity of fissile material in the

sample. For large samples the self-shielding phenomena limit the “visibility” of fissile material to the interrogating neutrons, causing saturation effects in the response function and underestimation in the quantity of the fissile material (unless the calibration is designed to take the effect into account). This self-shielding effect is one of the major contributors to the systematic assay error of active neutron techniques.

2.2. Measurement technique / Description of the implemented technique

Apart from the presence of the interrogating source, the methods and procedures of shift-register based instruments for active neutron coincidence counting are very similar to those used in passive neutron coincidence counting (PNCC).

There are basically two major families of instruments in this category:

- the Neutron Coincidence Collar (NCC) in active mode;
- the Active Well Coincidence Counter (AWCC).

Neutron collars are typically composed of four slab detectors in a square arrangement, and are used for the assay of fresh fuel assemblies. Some models have a modular layout allowing the adjustment of collar dimensions to the fuel element size, others have fixed configurations for specific fuel type (PWR and BWR). Collars can be used both in passive and active mode. For passive only applications (MOX fuels) normally all the four sides are equipped with detectors, for active/passive applications (LEU fuels) only three detection slabs are used and the fourth wall hosts the source.

Active well coincidence counters are general-purpose devices for uranium bearing samples at practically any enrichment (HEU and LEU), chemical form (metal, oxide) and physical form (powders, pellets, plates, MTR elements). An AWCC is conceptually similar to a passive high-level neutron coincidence counter (HLNCC) except for the presence of two AmLi sources in the top and bottom polyethylene plugs. It can be operated either with or without a cadmium liner (thermal or fast mode).

Table I: Performance values for the determination of the ^{235}U mass loading in fresh LEU fuel elements (1000 s counting time).

Technique	Objects	Enrichm.	r(%)	s(%)
NCC (active mode)	UO ₂ Fuel Elements for LWR	Up to 3%	1	1 – 2
	UO ₂ Fuel Elements for LWR	3 – 5 %	1	2 – 4
	LWR fuels with burnable poisons	any	1	3 – 5

Table II: Performance values for the determination of the fissile content in U samples.

Technique	Objects	r(%)	s(%)
AWCC	HEU Metal	2	3
	HEU Powder (fast mode)	2	10
	HEU Powder (thermal mode)	2	5
	UF ₄ Salt	5	2
	HEU/Th/C Pebbles	2	4
	HEU/AI MTR	1	3
	LEU Powder (fast mode)	2	5

By extending the shift register electronics it is possible to operate ANCC systems in multiplicity mode. This is exactly analogous to the extension from PNCC to passive neutron multiplicity counter (PNMC). Under certain conditions three unknown quantities can then be determined instead of just two. This allows, for example, a variable detection efficiency (perhaps due to variable moisture content) to be taken into account in the interpretation model. The use of multiplicity counting in ANCC systems is still undergoing development.

2.3. Performance Values for Passive Neutron Measurements

Performance values for the assay of the fissile uranium content obtained with two common instruments (NCC and AWCC) from different materials are given in Tables I and II, essentially based on field experiences [2,3]. The two components to the total uncertainty are split: random (r) and systematic (s). Note that these values assume that an adequate calibration exists, for each material type quoted. The systematic uncertainty for the fast mode assay is generally higher than for the thermal mode, due to the range of matrix effects, although the potential for gross assay underestimation is greatly reduced in fast mode.

3. Other fields of application

Active neutron interrogation techniques can also be used for other purposes, for instance waste characterisation.

4. Additional information and useful links; references

- 1 D. Reilly et al., "Passive Nondestructive Assay of Nuclear Materials", NUREG/CR-5550, LA-UR-90-732, March 1991.
- 2 G.P.D. Verrecchia, B.G.R. Smith, S. Guardini, "The calibration of four Euratom active well coincidence counters for a wide range of high enriched uranium material", Proc. of the 11th ESARDA Symposium on Safeguards and Nuclear Material Management, Luxembourg, 30 May -1 June 1989.
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Web sites:

<http://www.canberra.com/products/714.asp>

www.ortec-online.com/nda/awcc.htm

Active Well Coincidence Counter (AWCC)



Uranium Neutron Coincidence Collar (UNCC)



Calorimetric Techniques for Pu Mass Determination

1. Objective of the technique

1.1. Objectives

Calorimetry is a technique for measuring the thermal power of heat producing samples. Radioactive decay of any radioactive material produces heat. Calorimetry may be used to measure the thermal power of plutonium samples. The quantitative determination of plutonium by calorimetry is based on the measurement of the heat produced by the radioactive decay of the Pu isotopes, in combination with the knowledge of the Pu isotopic mass ratios. Calorimetry provides a convenient, accurate and non-destructive measure of the total plutonium mass in samples of unknown composition.

1.2. Scope of applications

Calorimetry has many advantages with respect to other NDA techniques and it is potentially the most accurate non-destructive method for measuring plutonium: calorimetry does not suffer from neutron multiplication effects that hinder other measurement methods and corrections are not required for sample in-homogeneity or chemical form. Unlike destructive analysis, where it is only possible to assay selected samples taken from the item, calorimetry, as other NDA techniques, allows the measurement of the whole item.

Due to long time needed for reaching the thermal equilibrium, this is not a routine technique for safeguards. It is a "laboratory" technique.

2. Presentation of the technique

2.1. Principle of Measurement

Plutonium isotopes decay emitting α, β, γ particles, of which the α, β particles are responsible for the heat generated in the surrounding sample matrix. The calorimetric plutonium assay needs information on the content of ^{241}Am in the measurement item, which also contributes to the measured thermal power and which, as a decay product of ^{241}Pu , is present in practically all plutonium samples.

In Table 1 the specific thermal power values of the Pu isotopes (and of ^{241}Am and ^3H) are recorded.

Table 1: Specific thermal power values (from ref [1,2])

Isotope	Main Decay Mode	Specific Power (mW/g)
^{238}Pu	α	567.57
^{239}Pu	α	1.9288
^{240}Pu	α	7.0824
^{241}Pu	β	3.412
^{242}Pu	α	0.1159
^{241}Am	α	114.2
^3H	β	324.

2.2. Measurement Technique

The thermal power W (Watts) measured from a plutonium sample in a calorimeter is converted into the plutonium mass (grams) as following:

$$m_{\text{Pu}} = \frac{W}{P_{\text{eff}}}.$$

The specific thermal power P_{eff} (W/g) of the plutonium sample is calculated from the expression:

$$\text{where: } P_{\text{eff}} = \sum_i R_i \cdot P_i$$

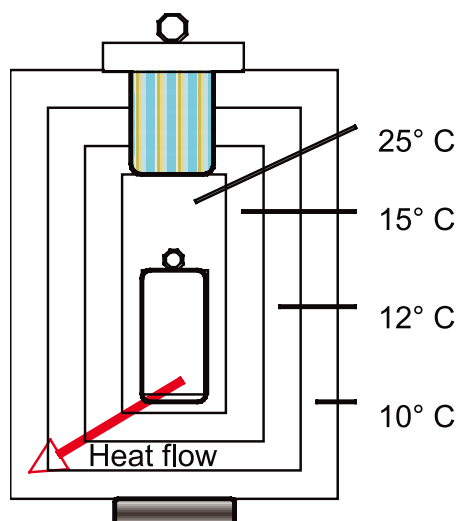
R_i = abundance of the i -th isotope ($i = ^{238}, ^{239}, ^{240}, ^{241}, ^{242}\text{Pu}$ and ^{241}Am) expressed as a weight fraction ($g_{\text{isotope}}/g_{\text{Pu}}$) and

P_i = a physical constant, the specific thermal power of the i -th isotope in W/g.

One of the most common types of calorimeter in use across the world today for nuclear measurements is the isothermal (servo-controlled) calorimeter.

The calorimeter works by maintaining an isothermal enclosure whereby the temperature profile of the calorimeter is kept constant by electrical heaters. Following insertion of the (Pu) heat bearing source, the reduction in the applied electrical power required to preserve static temperatures is a measure of the decay heat rate.

The measurement chamber of the calorimeter is contained in the thermal element (Fig 1). The thermal

Fig 1 Schematic view of an isothermal air-flow calorimeter

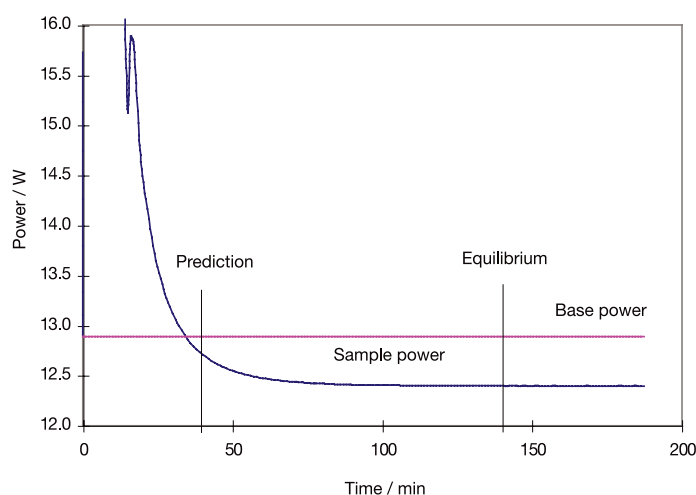
element consists of a concentric arrangement of three aluminum alloy cylinders, separated by silicon based thermal semi-conductors. Appropriate nickel resistance thermometer sensors and heater windings, placed inside machined grooves on each of the cylinder surfaces, undertake temperature measurement and control.

The measurement principle involves determining the difference in electrical power supplied to the inner cylinder, to maintain a constant cylinder temperature, after a heat bearing sample is placed into the chamber. As the associated thermal energy is gradually transferred to the inner cylinder by heat conduction and as the inner cylinder must remain at a fixed temperature, the servo controller automatically reduces the applied electrical power. After a period of time, a new thermal equilibrium is achieved (Fig. 2). The difference between the old (baseline) and new inner cylinder applied electrical powers being equal to the sample power.

Due to the long time required to reach the thermal equilibrium, the technique is sensitive to the possible change of environmental conditions during the assay. A nearly constant external room temperature is essential for a good performance. This is another reason that makes calorimetry preferably a laboratory technique not suitable for industrial environment. In this frame it is possible to improve the measurement performance by placing the instrument in a controlled environment, such as a climatic chamber.

2.3. Performance Values

The performance of a calorimetric plutonium assay depends on the thermal power W as determined by

Fig 2 Servo-controlled electrical power applied to calorimeter

the calorimeter and on the quantity P_{eff} as derived from an external isotope abundance measurement.

Table 2 gives typical performance data [3] for the thermal power measurement obtained with large sample calorimeters and with the new generation of small sample calorimeters using thermopile sensors or combinations of thermopiles and Ni thermocouples (Hybrid calorimeters). The dominant contributions to the random and systematic uncertainties for the small sample calorimeters are due to heat distribution errors and baseline fluctuations.

Table 2: Performance of thermal power measurement. (from [3])

Calorimeter	Thermal power level (W)	r (%)	s (%)
Large sample calorimeter (Ni thermocouple)	0.1	0.4-0.7	0.1-0.2
	1	0.1-0.3	0.05-0.2
	10	0.05-0.07	0.05-0.2
	100	0.05-0.07	0.05-0.2
Small sample calorimeter (Thermopile)	0.001	0.8-1.0	0.2-0.5
	0.01	0.1-0.3	0.1-0.2
	0.1	< 0.1	0.1

The above reported performance values refer only to the direct measurement of the thermal power. The total random and systematic uncertainty of a calorimetric plutonium assay is obtained from a combination of the respective uncertainty components for the thermal power and P_{eff} determination. This second component is mainly affected by the uncertainty in the isotopic composition and in particular of the isotopic fractions of ^{238}Pu and ^{241}Am that are the two main contributors,

Fig 2 Plutonium air-flow calorimeter

therefore it will depend on the technique used for isotopic assay (typically gamma spectrometry).

3. Other fields of application

4. Additional information and useful links-References

- 1 ASTM-Standard C 1458-00, "Standard Test Method for Nondestructive Assay of Plutonium, Tritium and ²⁴¹Am by Calorimetric Assay".
- 2 D. S. Bracken, R. S. Biddle, L. A. Carillo, P. A. Hypes, C. R. Rudy, C. M. Schneider, M. K. Smith, "Application Guide to Safeguards Calorimetry", LA-13867-M (2002).
- 3 S. Guardini (Editor), "Performance values for non destructive assay (NDA) techniques applied to safeguards: The 2002 evaluation by the ESARDA NDA working group", ESARDA Bulletin Ner 31, November 2003

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Gamma Spectrometry for U and Pu Isotopic Determination

1. Objective of the technique

Gamma spectroscopy is the most commonly used Non-destructive Assay (NDA) technique in nuclear safeguards to measure uranium enrichment and plutonium isotopic composition [1].

2. Presentation of the technique

2.1. Principle of measurement / Definition of the physical principle

The decay of radioactive nuclides is often accompanied by the emission of one or more photons whose energy is characteristic of the nuclide itself. Gamma spectrometers are equipped with detectors appropriate for measuring the photon energy. Therefore, a gamma spectrum can be used to identify the gamma emitting isotopes in a material by correlating the photopeaks to the characteristic energies of each nuclide. Moreover, the comparison of different peak intensities can be used to derive the relative abundance of isotopes.

There are several types of gamma spectrometer, with different applications [2]. The most common types used in safeguards applications are:

- inorganic scintillators, mostly NaI(Tl) detectors
- semiconductor detectors, such as high-purity germanium (HPGe) or cadmium-zinc-telluride (CZT).

In a scintillator, the interaction of the photon with the crystal results in the excitation of atoms to higher-energy states, followed by their immediate relaxation with consequent emission of the excitation energy in the form of light. This light is collected on a photocathode, composed of a material with a high probability of photoelectric effect, resulting in the emission of a number of electrons proportional to the energy of the original photon. These electrons are then increased in number by successive acceleration in an electric field and collisions on metallic dynodes, finally resulting in a charge burst hitting the anode of the photomultiplier tube.

In a semiconductor, the photon "ionises" the crystal (i.e., by generating electron-hole pairs), and this results in a collection of charge at the electrodes, if a voltage is applied to the semiconductor.

In both cases, the interaction of a photon with the detector results in an electric signal, whose intensity is proportional to the energy of the incoming photon.

The analogue signal is then processed in a pulse processing electronic chain. This typically consists of an amplifier, an analog-to-digital converter (ADC) and a multi-channel-analyser (MCA) that produces the gamma spectrum. The gamma spectrum is simply the number of photons detected in a preset number of channels, each channel corresponding to an energy band. The analogue modules may also be integrated into a single compact module, such as the MMCA (Mini Multi-Channel Analyser). Recently, the traditional analogue electronics have been replaced by digital electronics, and DSP (digital signal processor) modules are now available.

Finally, the spectrum is analysed in a PC using specialised software, performing peak fitting, background subtraction, peak intensity calculation, external or intrinsic calibration and calculation of the relative isotopic abundance.

2.2 Measurement technique / Description of the implemented technique

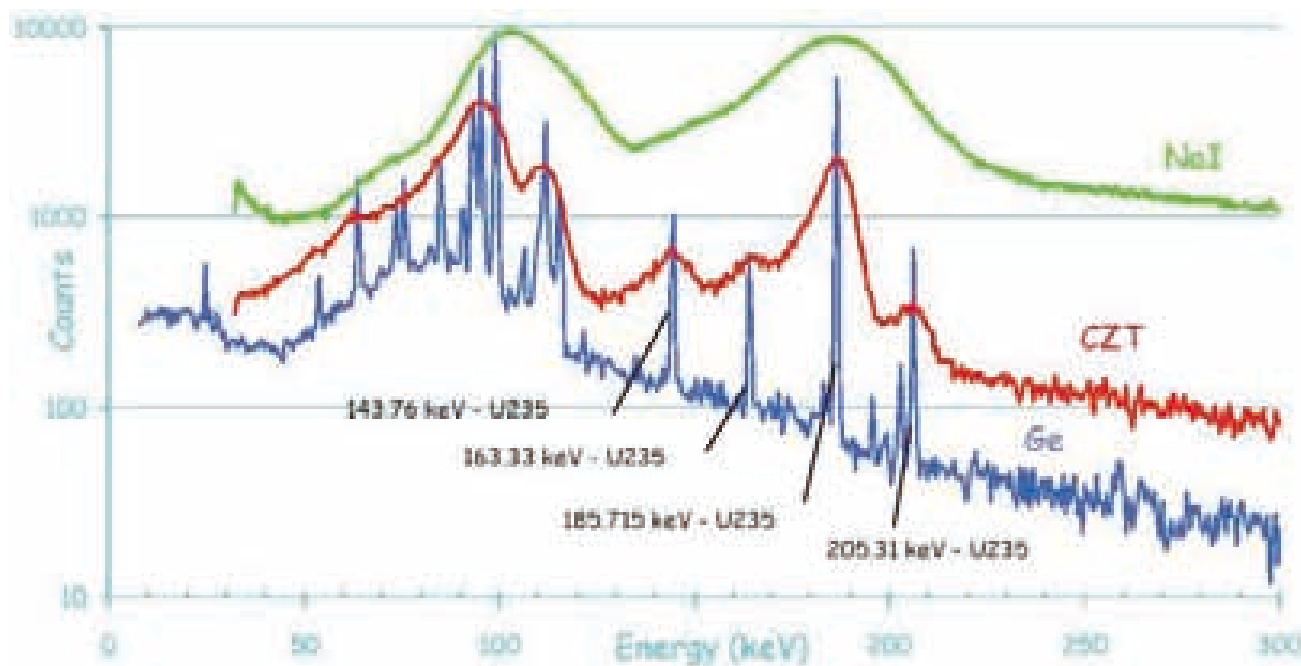
a) Acquisition of gamma spectra

Scintillators in general, and NaI in particular, are characterised by a high detection efficiency, counterbalanced by a poor energy resolution¹. Due to this last feature they are not suitable for cases involving complex spectra with many closely spaced gamma lines, such as plutonium. The use of NaI detectors in nuclear safeguards, often referred to as Low Resolution Gamma Spectrometry (LRGS), is therefore limited to the measurement of ²³⁵U enrichment in uranium samples.

High Resolution Gamma Spectrometry (HRGS) is the preferred technique for plutonium isotopic determination, although it can also be applied to

¹ Due to the statistical nature of the physical processes involved in the conversion from photon energy to electric pulse, a photon with a well-determined energy generates an electric pulse whose intensity can fluctuate around an average value. This results in a broadened peak shape in the spectrum instead of a line. The resolution of a detector is defined as the ratio between the full-width-at-half-maximum (FWHM) of the peak and the photon energy.

Figure 1 – Comparison of uranium spectra from different detector types [3]



measure uranium enrichment. HPGe detectors have by far the best energy resolution. Unfortunately, germanium crystals cannot be operated at room temperature. To guarantee an appropriate semiconductor behaviour, the germanium crystal has to be maintained at very low temperatures, i.e., typically using liquid nitrogen (77 K) or electro-mechanical systems. Due to the required cooling, germanium detector units tend to be relatively heavy and large (see photos at the end of this paper).

For applications where portability or accessibility is an important requirement, other types of crystal have been introduced, such as Cadmium-Zinc-Telluride (CZT), which exhibits semiconductor behaviour at room temperature. CZT detectors have a lower energy resolution than Ge-detectors and are used to measure uranium enrichment and to perform attribute verification of spent fuel (detection of fission products). Figure 1 shows a comparison of typical spectra as generated from different types of photon detector.

b) Analysis of gamma spectra

Once a spectrum has been acquired it has to be evaluated, in order to derive the isotopic composition. There are basically two methods available for the analysis of spectra:

- infinite thickness method (or enrichment meter principle)
- intrinsic calibration method.

The infinite thickness method is applied only for uranium enrichment measurements, and it is based

on a calibration using reference samples. According to this approach, the most prominent gamma transition of 185.7 keV from the decay of ^{235}U is measured under a well-defined geometry (i.e., solid angle of the sensitive detector volume relative to the gamma source). The measured counting rate of the 185.7 keV photons is proportional to the ^{235}U abundance. The required infinite sample thickness ranges from about 0.25 cm for metal samples to about 7 cm for UF_6 with a density of 1 g/cm³. The method is best suited for bulk samples (e.g., uranium oxides and fluorides in storage containers), which easily meet the infinite thickness requirement. Enrichment measurements based on the enrichment meter principle require physical standards containing a sufficiently large amount of uranium reference material for calibration.

Measurements based on the intrinsic calibration method avoid the need for calibration with physical standards. Here, the isotopic ratios are determined from the measured gamma spectrum using corresponding gamma and X-rays from the decay of all isotopes, taking into account physical phenomena such as the energy dependence of detector efficiency, self-absorption in the sample and attenuation in the container and filters. For plutonium spectrum analysis, a major advancement for the measurement technique was achieved with the development of the Multi-Group Analysis (MGA) code, which successfully exploits the complex XK_α region (94-104 keV) of a plutonium gamma spectrum for the isotope analysis [4]. Since this spectral region contains the most abundant plutonium gamma and

Table 1 – Performance values for gamma-spectrometric enrichment measurements on low-enriched uranium oxide materials

²³⁵ U Enr.	Infinite thickness method									Intrinsic calibration method					
	HRGS (Ge detectors)			LRGS (NaI detectors)			CZT			HRGS (Ge detectors)			CZT		
	CT (s)	r (%)	s (%)	CT (s)	r (%)	s (%)	CT (s)	r (%)	s (%)	CT (s)	r (%)	s (%)	CT (s)	r (%)	s (%)
0.3 to 0.7%	360	2	1	360	3	1	1200	10	1	360 3600	8 3	5 5	ns	ns	ns
2 to 4 %	360	0.7	0.5	360	1	0.5	1200	3	1	360 3600	2 1	1 1	10 ⁴	10	5
5 to 10 %	360	0.5	0.5	360	0.5	0.5	1200	3	1	360 3600	2 1	1 1	10 ⁴	10	5

Table 2 – Performance values for Pu isotope assay in PuO₂ and MOX

Type of plutonium	Isotope	r (%)	s (%)
Low burnup	²³⁸ Pu	3	5
	²³⁹ Pu	0.2	0.1-0.2
	²⁴⁰ Pu	1	0.3-1
	²⁴¹ Pu	1	0.2-0.6
	²⁴¹ Am	1	0.5
High burnup	²³⁸ Pu	1	1
	²³⁹ Pu	0.5	0.2-0.4
	²⁴⁰ Pu	1	0.5-1
	²⁴¹ Pu	1	0.5-1
	²⁴¹ Am	1	1

X-rays detectable in a gamma spectrum from plutonium in the presence of Am, use of MGA code enables relatively precise isotope abundance determinations from gamma spectra accumulated in relatively short counting times (15-30 min). For uranium spectra, the method again uses analysis of the XK region (89-99 keV), where fairly abundant but strongly overlapping gamma and X-ray signatures from the ²³⁵U and ²³⁸U daughter nuclides ²³¹Th and ²³⁴Th occur. This approach requires secular equilibrium between ²³⁸U and its daughter nuclides, which is reached about 80 days after chemical separation: the method is, therefore, not suited to freshly separated uranium materials.

A drawback of the gamma-spectrometric technique is the lack of measurement capability for the isotope ²⁴²Pu. Because of its very low specific gamma activity, ²⁴²Pu does not manifest itself with a detectable gamma-ray signature in a plutonium gamma spectrum. Therefore, recourse has to be made to isotope correlation techniques for an estimate of the abundance of this isotope. The uncertainty in the estimated ²⁴²Pu abundance reduces the overall accuracy of a complete gamma-spectrometric plutonium isotopic analysis made on materials containing a notable fraction of this isotope.

2.3. Performance Values for gamma spectrometry

For uranium enrichment measurement there is a variety of methodological possibilities according to the choice of the detector (NaI, HPGe or CZT) and of the analysis method (enrichment meter or intrinsic calibration). Table 1 compares typical performance values of the possible combinations [4] as a function of the enrichment range. In this table CT stands for counting time in seconds, and “r” and “s” stand for the contributions to the measurement uncertainty derived from the statistical (random) and systematic components respectively.

For plutonium isotopic composition the choice of HPGe in combination with intrinsic calibration is the only option available. Table 2 shows typical performance values for HRGS technique for different plutonium compositions. The random component of the uncertainty is based on the assumption of a typical counting time of 10 to 20 minutes. The systematic uncertainty is estimated based on the use of a well-known isotopic ratio of ²⁴²Pu. If this value is not known, and has to be computed from isotopic correlations, the systematic uncertainty can increase significantly, being dominated by the uncertainty of the ²⁴²Pu content.

Germanium detectors with dewars for liquid nitrogen cooling



Gamma spectrometer with liquid nitrogen-cooled germanium detector, Mini Multi-channel Analyser, and Hewlett Packard LX200 palmtop computer



3. Additional information and useful links; references

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Web sites:

http://www.ortec-online.com/detectors/photon/b2_3.htm

<http://www.ortec-online.com/papers/reprints.htm#Nuclear>

<http://www.canberra.com/products/465.asp>

<http://www.canberra.com/literature/>

Monte Carlo Simulation applied to non-destructive assay techniques

1. Objective of the technique

Monte Carlo simulations are commonly applied to non-destructive assay (NDA) systems both as a design tool for NDA equipment, to optimise its performance and to predict its response in different configurations, and as a computational calibration technique. Computation codes based on the Monte Carlo method allow the modelling of complex geometries in three dimensions and determination of the response of an NDA instrument without the need for nuclear standards.

2. Presentation of the technique

2.1. Principle of Monte Carlo simulations

The Monte Carlo method does not solve an explicit equation, but instead obtains answers by simulating individual particles and recording aspects of their behaviour. Numerous particles are followed from their emission by a source, through to their loss by absorption or leakage. The trajectory of each particle is broken down into sequences comprising free flight and, at a given moment, a collision whose nature is randomly selected from a set of possible reactions in the material, the assigned probabilities being related to the cross sections of the material in question.

The behaviour of real particles within the physical system is predicted from the accumulated data on a large number of simulated particles, and the response of the NDA instrument is determined from the statistical mean of the behaviour of the population of the simulated particles. This technique is well suited to solve complicated three dimensional and time dependant problems, because no averaging approximations are required in space, energy or time.

Thus an NDA system can be modeled and the expected response from the detection system can be calculated. The simulation can be applied to a range of detectors (high purity germanium detector in the case of gamma spectrometry, ^3He detectors in the case of neutron counting devices), used with a variety of radioactive sources including containers holding nuclear materials and drums containing neutron- and gamma-emitting waste.

2.2. Monte Carlo simulation technique

Implementation of a Monte Carlo computational code requires the preparation of an input file that describes the geometry of the system in three dimensions, the materials, the associated cross-sections libraries (built using standard nuclear data evaluations), the location and characteristics of the emitting source, the type of results desired and the conditions for running the calculation.

The code MCNP [1], considered as an international standard code for neutron, photon and electron transport modelling, is commonly used in support of the design and calibration of NDA systems for nuclear material safeguards applications. The user can instruct the code to make various tallies related to particle currents, particle flux, reaction rates in different points, surfaces or volumes of the system and energy depositions. Each tally is given by the code with a statistical relative error, representing the precision of the Monte Carlo calculation. Depending on the number of particles generated, the error can be as small as desired by the user, given sufficient time to complete the calculation. In addition to the tally information, the output file also contains tables of standard summary information that can help the user to determine the confidence in the results.

Example 1: modelling of an experimental gamma-ray spectrometry system:

The experimental gamma ray spectrometry system presented in **Figure 1** is used to quantify plutonium masses present in waste drums. The MCNP computation code enables estimation of the energy spectrum of the photons detected in the detector's germanium crystal (**Figure 2**) for any gamma source facing it. The energy deposition from those electrons generated by the photons impinging upon the detector is calculated, for each emitted photon, from:

- a 3D description of the detection system formed by the detector, its stand and collimator, in its measuring environment (**Figure 3**). This model incorporates the physical (density), chemical (stoichiometry) and nuclear (cross sections) data characteristic of each material; and



Figure 1:
gamma spectrometry system

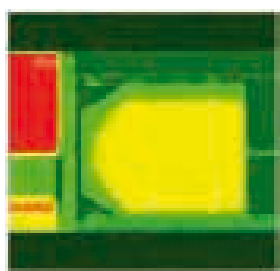


Figure 2:
radiography of the crystal

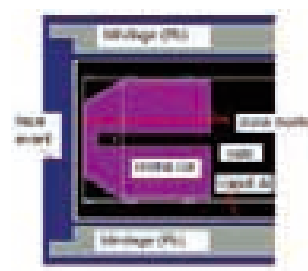


Figure 3:
axial section

- a geometrical description of the photon source, its location in relation to the detector and the definition of its emission.

Depending upon how complex the photon source is (i.e. calibration source or nuclear material), one or two calculation stages may be required in order to estimate the spectrum. In the case of nuclear material, the effect of self-absorption can lead to a requirement for a two-stage calculation process, for reasons of statistics and computing time. This two-stage process comprises calculating the photon flow from the radioactive object at the input side of the detector, then calculating the detector's response to this flow at normal incidence.

The modelling validation phase entails establishing a calibration curve for the efficiency of the gamma-ray spectrometry system. The calibration is carried out experimentally using a certified ^{152}Eu source, particularly useful because its γ emission spectrum is spread over an energy interval ranging from 121–1408 keV (spectrum **Figure 4**). The model can be improved, by giving a very accurate description of the detector's shape and by adjusting the peripheral dead zone thickness in the manufacturer's recommended range, to obtain constant deviation for all the ^{152}Eu lines. The calibration curve produced is presented in **Figure 5**, showing relative deviations between the experimental efficiencies and those set by MCNP of between - 2% and +4% for the main ^{152}Eu lines.

Such a model can be applied to the calculation of spectra relating to real plutonium waste drums, for measurement feasibility studies. In this case, allowance can be made for the container, the matrix comprising the drum (physical and chemical composition, density, homogeneity), the radioactive material (activity level, position) and the presence of other, more intense, gamma-ray emitters (fission and activation products) when evaluating the detection limits of the NDA system.

In gamma spectrometry, Monte Carlo simulations can also be used to determine the function of energy

transfer, and to evaluate the influence of the geometry of the system (i.e. source to detector distance, photon attenuation in packages or screens, collimation system), for each energy.

Example 2: modelling of an experimental neutron counting system:

The passive neutron counting system shown in **Figure 6** is used to measure plutonium held in large-dimension containers. The MCNP computation code enables an estimation of the neutrons detected by the neutron counting system for any neutron source placed inside the measuring cavity. The code calculates the number of neutron captures (n, p) occurring in the active parts of the twelve detectors, for a neutron emitted by the neutron source. The code employs:

- a 3D description of the measuring chamber (**Figures 7 and 8**), including the physical (density) and chemical (stoichiometry) and nuclear (cross sections) characteristics of the materials; and
- a geometric description of the neutron source, its location in the sample cavity and the definition of its emission.

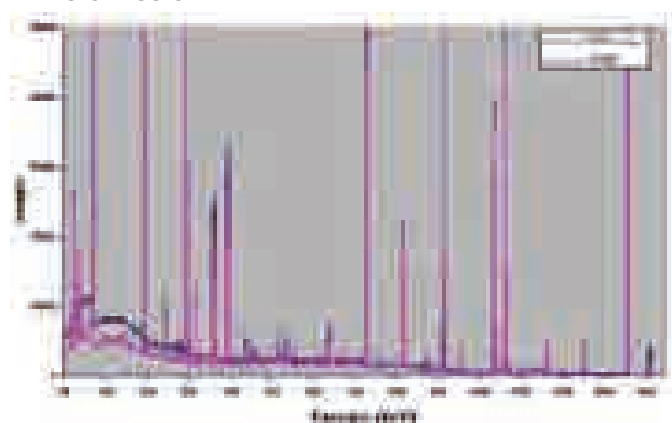


Figure 4 : ^{152}Eu spectrum

The modelling process goes through an initial phase, to assess the quality of the model through examination of some characteristic parameters of the NDA system. This entails comparing practical measurements of the detection efficiency and

Figure 5 : efficiency curve

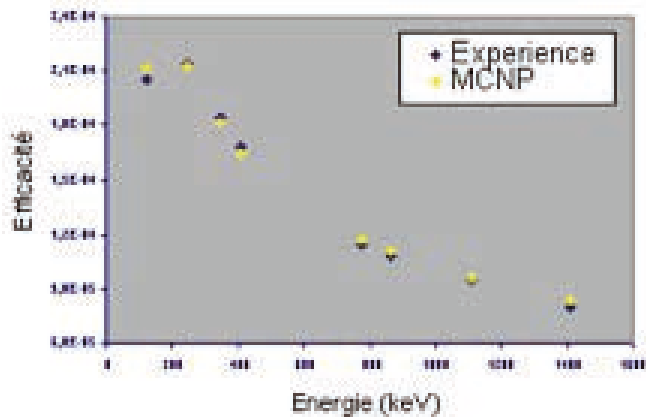


Figure 6: neutron counting system

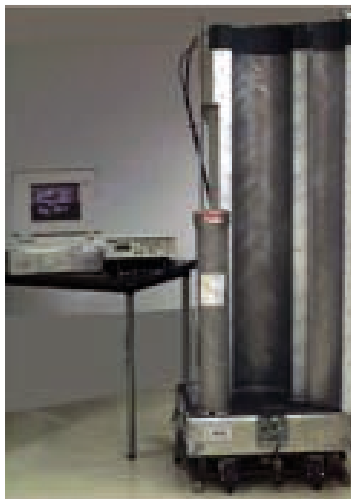


Figure 7: axial section



Figure 8: radial section

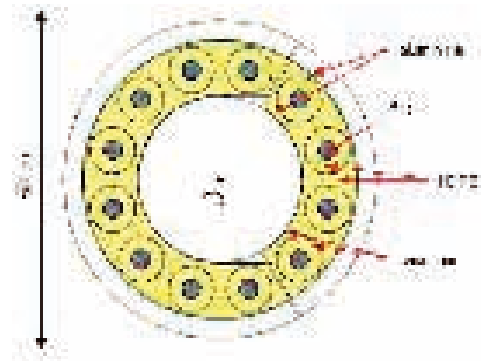


Figure 9: axial profile of totals

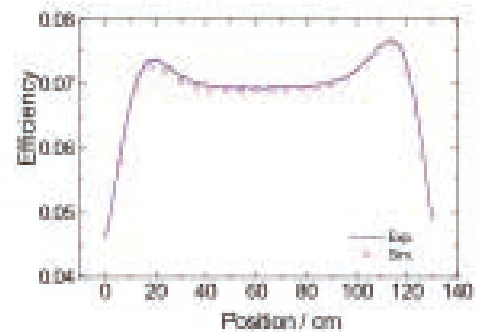
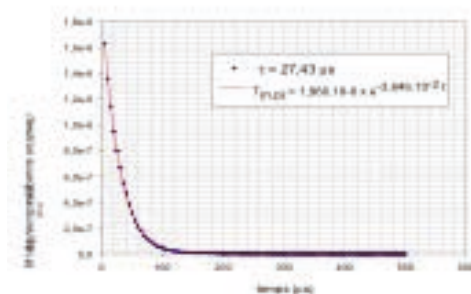


Figure 10: neutron lifetime



neutron lifetime, using a calibration source of ^{252}Cf , against the simulated parameters. **Figure 9** shows the efficiency axial profile, obtained experimentally and by MCNP simulation, illustrating a 2% deviation in the simulated results from the experimental values. **Figure 10** presents the evolution of the number of (n,p) captures in the detectors over time, obtained by simulation with MCNP, for a source of ^{252}Cf centered in the sample cavity. The number of neutrons present in the device drops exponentially over time, with a mean lifetime of λ , with a 3% deviation in the simulated results compared with the experimental values.

A model is built as realistically as possible, but it is very hard to describe accurately all the components of the measurement system. Because it is important to have a thorough knowledge of the materials that

form the neutron moderator and absorber, hypotheses and verifications are made in order to arrive at a better description. In the case of the detector tubes, the manufacturers give some parameters, such as the active length or fill pressure, but wall thickness and material, end caps and added gases are harder to establish. As the quality of the simulation is a function of the approximations made, parametric studies are used to quantify the influence of data known to be inaccurate and its uncertainty on the result. A compromise has to be found between the detail of the description and the required accuracy.

Such a model can be applied to calculation of the neutron count rates relating to large plutonium samples, and new Monte Carlo codes based on MCNP, such as MCNP-PTA or MCNPX, are being developed for this purpose. Neutron pulse trains are generated in the Monte Carlo simulation, and analysed in a simulated shift register in order to predict the expected singles, doubles and triples that would need to be measured experimentally in order to quantify plutonium [2]. The simulations performed with such modified MCNP codes give the opportunity to carry out a calibration when a fully representative standard for experimental calibration is not available.

3. Performance

Upon completion of a Monte Carlo simulation, the computational code used gives a statistical uncertainty dependent upon the number of particles that contributed to the result, so that the correct convergence of the calculation can be checked. The selection of a statistical error criterion often results from a compromise between calculation time and the required accuracy of the result. But this is not the only contribution to the overall uncertainty of the simulated quantity, and this error does not represent the accuracy of the result compared to the true physical value.

Monte Carlo simulation is limited by the validity of the assumptions and the accuracy of the model used. These limitations come from the level of detail of the geometry model, the accuracy of each input data used during the calculation (material data, nuclear data), the physics treatments and any other interpretational models used to convert calculated quantities into a representation of the instrument response. The uncertainties arising from the differences between modelling and reality (description simplifications, lack of knowledge of some data etc) are estimated using both sensitivity studies, by assessing which relative influence of

variation in each parameter on the result, and benchmarking against experience.

Example 1 (modelling of an experimental gamma-ray spectrometry system):

To obtain good agreement between calculation and experience, very accurate information is required on: the detector (geometry, dead zones); the shielding (composition, density); the sources (mass, density, composition, geometry); the containers; and the matrix, if any. The study performed showed an uncertainty on the detector efficiency above 100 keV of about 5% if the geometry of the crystal was accurately known. The modelling of plutonium oxide samples with a relatively well known geometry presented an uncertainty of about 20% on the net area of total absorption peaks from 129 keV to 451 keV.

Example 2:

A parametric sensitivity study of the nuclear (spectra, cross sections), geometric (^3He detectors position, tubes thickness), physical (density), chemical (composition) and environmental data (repository premises) lead to an overall uncertainty on the detection efficiency of the system of about 5%. Modelling of plutonium oxide samples with a well-known geometry and a plutonium mass from 8 to 2500 g gave an accuracy of about 2 % on the total neutron rates.

The ESARDA NDA WG organised a simple benchmark exercise [3] involving a neutron slab monitor, to study the influence of the nuclear data, physics treatments and geometry model approximations employed by commonly used Monte Carlo codes and to demonstrate the typical level of agreement with measurement that might be achieved for a simple neutron case. The results showed that Monte Carlo modelling could achieve agreement to within 5% of that from experiment, for simple geometries, with an uncertainty of about 3% due to geometry and physics treatments.

A previous benchmark exercise focused on the prediction of reals for a uranium oxide fuel assembly mounted inside the cavity of a neutron coincidence collar [4]. This indicated a performance value of 10% for the reals prediction techniques, based on an analogue Monte Carlo technique or on a modified form of the point model.

The ESARDA NDA WG is now working on a document describing recognised industry best practice techniques for the application of computer modelling tools in NDA.

4. Additional information and useful links

- 1 « MCNP – A General Monte Carlo N-Particle transport Code. Version 4B ». J. F. Briesmeister
LA – 12625 – M, Version 4B. Manual.
- 2 « Passive Neutron Coincidence Counting Techniques for Pu mass determination ». ESARDA technical sheet.
- 3 « Results of the Monte Carlo « simple case » benchmark exercise ». Patrick Chard
ESARDA symposium, 2003.
- 4 « Results of the ESARDA REALS prediction benchmark exercise ». P. Beaten et al.
ESARDA Bulletin N°31.

<http://laws.lanl.gov/x5/MCNP/index.html>

NB: a “Good Practice Guide for the use of computer simulations techniques in non destructive assay” is under construction by the ESARDA NDA WG.

Passive Neutron Coincidence Counting Techniques for Pu Mass Determination

1. Objective of the technique

Passive Neutron Coincidence Counting (PNCC) is a technique for determining (in combination with the knowledge of isotopic ratios) the mass of plutonium in unknown samples. PNCC is the most used NDA technique for Pu assay, being applied to a large variety of sample types: solid samples, liquid ones (less frequently), powder, metallic, pellets, fuel elements, waste drums, etc.

2. Presentation of the technique

2.1. Principle of measurement / Definition of the physical principle

The measurement of plutonium by passive neutron coincidence counting makes use of the fact that plutonium isotopes with even mass number (238, 240, 242) show a relatively high neutron emission rate from spontaneous fission. These neutrons are emitted simultaneously and are therefore correlated in time. The count-rate of time-correlated neutrons is therefore a (complex) function of the Pu mass.

The detection of pulse-trains of time-correlated neutrons uniquely identify spontaneous fission events among other neutron sources emitting neutrons which are randomly distributed in time, such as (α ,n) neutrons: this gives the possibility to determine the amount of plutonium in a sample. The isotope ^{240}Pu usually dominates the overall emission of spontaneous fission neutrons: ^{238}Pu and ^{242}Pu have comparable specific emissions (see table 1), but, in reactor-grade plutonium, their abundance is much lower.

The primary quantity, that is commonly determined in passive neutron coincidence counting, is an effective amount of ^{240}Pu , $m_{240\text{eff}}$, representing a weighted sum of the 3 even isotopes 238, 240 and 242:

$$m_{240\text{eff}} = a \cdot m_{238} + m_{240} + c \cdot m_{242}.$$

The coefficients a and c are the contributions of ^{238}Pu and ^{242}Pu to the neutron coincidence response in terms of an equivalent amount of ^{240}Pu .

For the conversion of $m_{240\text{eff}}$ into the total amount of plutonium, m_{Pu} , the isotopic mass fractions R_{238} , R_{240}

and R_{242} of the plutonium isotopes 238, 240 and 242 must be known (through γ -or mass-spectrometry) to calculate the isotope-specific quantity

$$^{240}\text{Pu}_{\text{eff}} = a \cdot R_{238} + R_{240} + c \cdot R_{242}.$$

The total amount of Pu is then evaluated as:

$$m_{\text{Pu}} = \frac{m_{240\text{eff}}}{^{240}\text{Pu}_{\text{eff}}}.$$

Table I : Spontaneous fission neutron yields

Isotope	Spontaneous fission yield (neutrons /sxg)
^{238}Pu	$2.59 \cdot 10^3$
^{239}Pu	$2.18 \cdot 10^{-2}$
^{240}Pu	$1.02 \cdot 10^3$
^{241}Pu	$5 \cdot 10^{-2}$
^{242}Pu	$1.72 \cdot 10^3$

2.2 Measurement technique / Description of the implemented technique

The spontaneous fission neutrons emitted by a Pu-bearing sample have an average energy of about 2 MeV. They are slowed down to thermal energies and detected with ^3He tubes, which are the standard neutron detectors. In practice all passive neutron coincidence counters (PNCC) systems are equipped with neutron moderating assemblies, built from moderating materials such as polyethylene, in which the ^3He tubes are embedded, in order to increase the detection efficiency. A high detection efficiency (provided also by large number of detectors) is important for coincidence counting, because it reduces the counting time and provides higher precision.

The most common hardware used in the PNCC systems for the extraction of simple coincidence rate ("doubles") from the pulse train produced by the ^3He detectors, is the 'Shift Register Analyser'. It represents a good choice for the measurement of smaller amounts of well-characterised product materials like Pu-metal or Pu-oxide exhibiting small and predictable neutron multiplication effects [1] as well as low and predictable (α ,n) production rates. For impure or inhomogeneous materials, such as scraps or waste, however, where corrections for multiplication, matrix and other effects become



**“Los Alamos”
High Level Neutron Coincidence Counter
HLNCC**

significant, the experimental information provided by the SR are not sufficient for a reliable and accurate Pu assay.

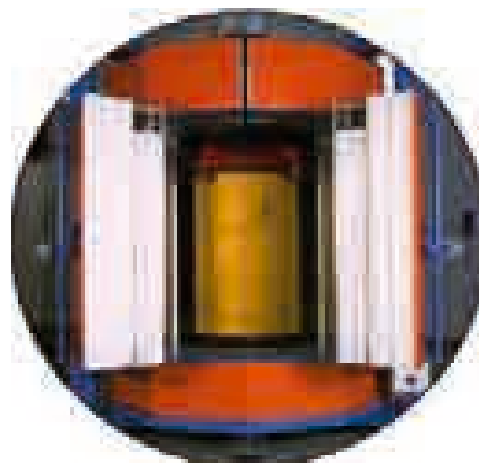
Passive neutron multiplicity counting technique (PNMC) has then been developed and it is increasingly applied in recent years [2,3], which provides an enlarged experimental information of 3 measured quantities: Singles, Doubles and Triples, which are the first three factorial moments of the counting rate. This allows extracting quantitative information on existing neutron multiplication effects from the measurement data.

With respect to conventional PNCC, PNMC allows to measure with better accuracy heterogeneous and poorly characterised materials and has the advantage that calibration does not require fully representative materials (i.e. multiplicity counters can be calibrated with standards completely different from the samples to be measured). The main disadvantage is the requirement of longer measurement time (or alternately higher detector efficiency) to get the necessary statistical precision on the Triples rate.

The research and development work for improved PNCC and PNMC techniques is still continuing. Some recent advances which have been achieved in the areas of interpretation of measurement results, detector technology, fundamental nuclear data, have resulted in notable improvements in measurement performance for certain applications.

2.3. Performance Values for Passive Neutron Measurements

PNCC is applicable to practically all kinds of Pu-bearing materials, but the majority of the measurements for Safeguards are carried out on



**“Ispra”
Passive Neutron
Waste Drum
Multiplicity Counter**

relatively pure and well characterized materials, such as, Pu-oxides and MOX materials (Pu-metal also, to a lesser extent). The amount of plutonium contained in this type of samples can typically range from the gram level up to several kilograms/sample. A second type of items falling into the category of product materials includes finished physical products like individual MOX fuel pins up to complete MOX fuel assemblies. Accordingly, a large variety of different neutron coincidence detection heads have been designed and optimised for the respective applications.

The major error sources contributing to the overall uncertainty are

- Counting statistics, which is a random component
- Calibration parameters and uncertainties in reference materials (systematic)
- Correction for multiplication effects, dead time, (α, n) neutron emission (systematic)
- Nuclear data.

Table II gives typical random (r) and systematic (s) error components for passive neutron counting of the most significant nuclear materials [4].

Table III gives the corresponding performance values for “impure” materials [4]

Table II: Performance values for $m_{240\text{eff}}$ measured in thermal passive neutron coincidence counters with shift registers

Nuclear Material Category	Pu Mass (g)	r (%)	s (%)
Pu Metal	$10^2 \sim 10^3$	0.5	1 – 2
PuO ₂	$10^2 \sim 10^3$	0.3	1 – 3
MOX Powders	$10^2 \sim 10^3$	0.3	3 – 5
LWR-MOX & FBR Fuel Elements		1	1 – 3

Table III: Performance values for $m_{240\text{eff}}$ measured in thermal neutron multiplicity counting mode

Material Category	SNM Mass (g)	(α,n)/SF rate	Counting Time (s)	r (%)	s (%)
Pu-Scrap	100 100-1200	5 1-6	1000 3600	12 4.5	1 – 5
Plutonium Residues	120 300 20-100 100	13-29 7-34 8-30 5-9	3000 3600 3600 3600	20 18.9 7 8.7	2 – 10
Plutonium Waste (estimated)	1 1 1	1 5 20	1000 1000 1000	2 10 50	1 – 2 2 – 5 5 – 10

3. Other fields of application

4. Additional information and useful links; references

- 1 K. Bohanel, "The effect of multiplication on the quantitative determination of determination of spontaneous fissioning isotopes by neutron correlation analysis"; Nucl. Sci. and Eng., 90, p 75-82, (1985)
- 2 D.M. Cifarelli and W. Hage: "Models for a three parameter analysis of neutron signal correlation measurements for fissile material assay", Nucl. Instr. And Meth., A251 (1986) 550-563.
- 3 N. Ensslin et al., "Application Guide to Neutron Multiplicity Counting", LA-13422-M (1998).
- 4 S. Guardini (Editor), "Performance values for non destructive assay (NDA) techniques applied to safeguards: The 2002 evaluation by the ESARDA NDA working group", ESARDA Bulletin Ner 31, November 2003

Web sites:

www.canberra.com/products/750.asp

www.ortec-online.com/nda.htm

Photon Absorption/Excitation Techniques

1. Objective of the technique

Absorption and excitation techniques using photons (X and gamma rays) are applied in nuclear safeguards mostly for determining element concentration in solutions [1].

2. Presentation of the technique

2.1. Principle of measurement / Definition of the physical principle

Classical absorptiometry is based on the measurement of the attenuation of a monoenergetic photon beam when passing through a material. The intensity of a beam crossing a medium is simply given by:

$$I(x) = I_0 * \exp(-\mu\rho x)$$

where I_0 is the initial intensity, μ the absorption coefficient, ρ the material density and x the thickness. Knowing the absorption coefficient and the thickness of the sample, its density (or concentration in solutions) can be derived by measuring the relative attenuation I/I_0 .

In nuclear safeguard applications, absorptiometry is more commonly applied using a different principle based on differential absorption in two gamma lines or in a continuous X-ray spectrum. This is possible because the photon cross sections of heavy elements have a quite peculiar behaviour in the range up to 150 keV. In this region the photon interaction with matter is dominated by photoelectric absorption whose probability is a rapidly decreasing function of energy interrupted by sudden increases in correspondence of the binding energies of the electron levels.

In K-edge densitometry (KED) the photon transmission through the sample under assay is measured at two photon energies which should bracket as closely as possible the K-absorption edge energy of the element of interest. The logarithmic ratio of the photon transmission measured below and above the absorption edge is directly proportional to the volume concentration of the measured element in the liquid and to the thickness of the investigated solution layer. The

latter parameter requires sample containers of well-defined path length holding the sample solution for the transmission measurements. KED provides an element-specific measurement because the K-absorption edge energy represents an element-specific signature.

X-Ray Fluorescence (XRF) is the most common photon excitation technique. It is based on the fact that in a nucleus irradiated with X or gamma rays electrons can be excited at higher energetic levels and then return to their ground state by emitting X-rays with energy that are characteristic of the element. By irradiating a solution containing U and/or Pu with the beam from an X-ray generator, the characteristic U and Pu X rays in the region 80-110 keV will be produced with an intensity that will be proportional to their elemental concentration.

2.2 Measurement technique / Description of the implemented technique

K-edge densitometry

In a K-edge densitometer, the actinide solution must be placed in a vial whose thickness is known with high accuracy. An X-ray beam from a generator (with typical energy of 150 keV) passes through the sample and the transmitted photon spectrum is recorded by a gamma spectrometer (typically a HPGe detector). The concentration of U (or Pu) is computed by the densitometry formula

$$\rho = \frac{\ln[T(E_-) / T(E_+)]}{\Delta\mu d}$$

where the T 's are the photon transmissions at energies immediately above (E_+) and below (E_-) the K-edge energy, d is the solution thickness and $\Delta\mu$ the difference of the absorption coefficient at E_+ and E_- (normally determined as calibration constant). This technique can be extremely accurate but it is not very sensitive (it has high detection limit), and it can be applied only to relatively concentrated solutions (> 50 g/l).

XRF densitometry

The XRF technique is applied if the element concentration to be determined falls below the

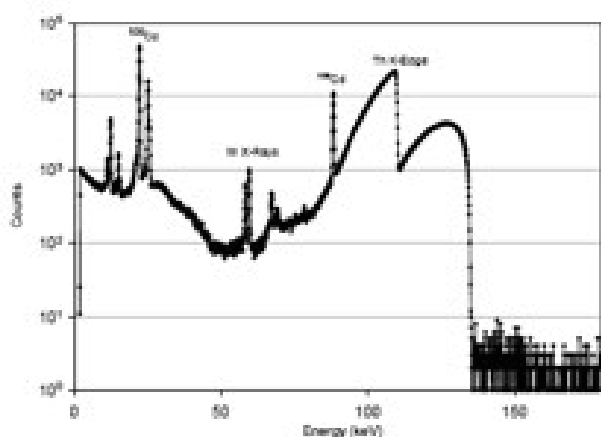


Figure 1 – Transmission spectrum in a K-edge

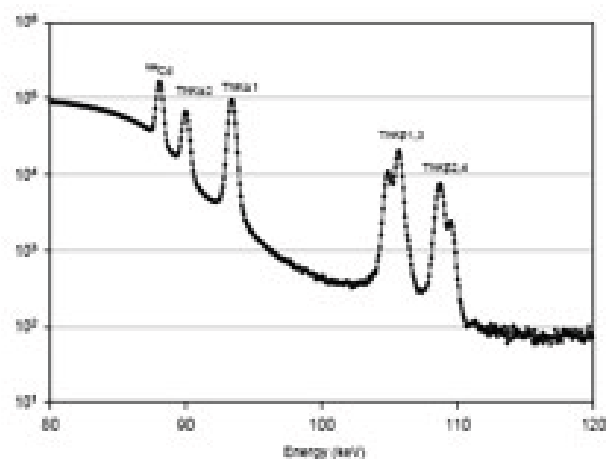


Figure 2 – XRF spectrum from U/Pu solution

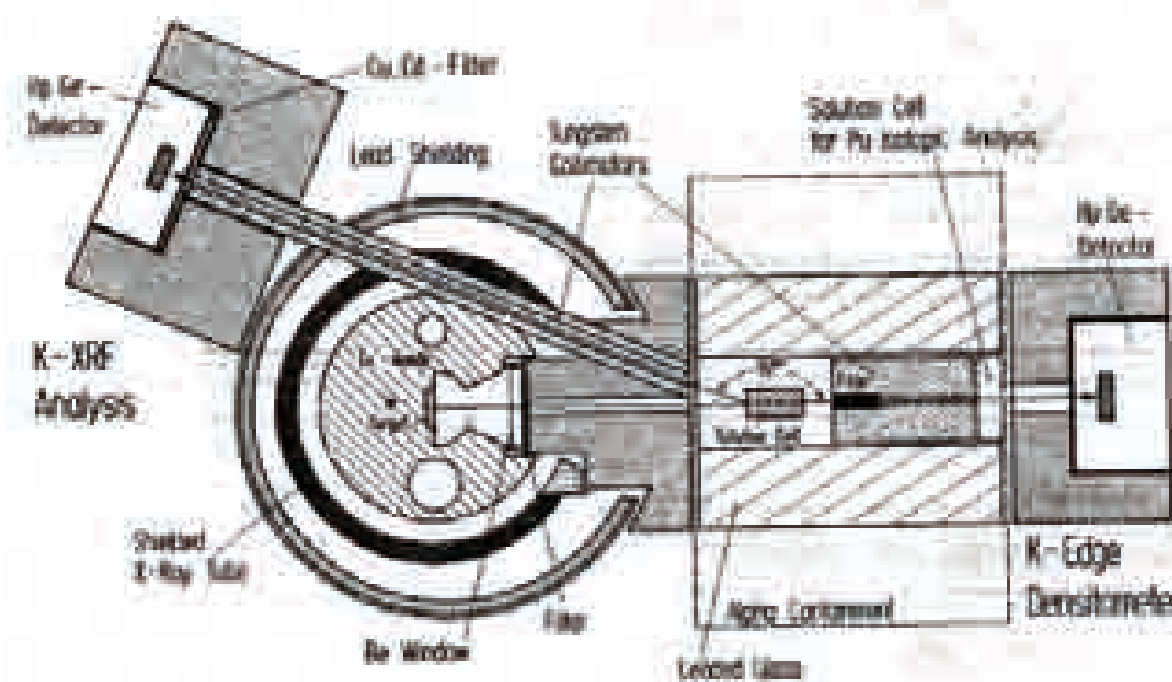


Figure 3 – Schematic view of a Hybrid KED/XRF densitometer

useful range for K-edge measurements. The energy-dispersive analysis of fluorescent K-X rays is applicable for quantitative concentration measurements down to concentration levels of about 0.5 g/l, with detection limits settled in the range of 0.02-0.05 g/l. The interpretation of the XRF measurements is not as straightforward as for KED, and it is also more sensitive to matrix effects. However, the XRF technique becomes very accurate for element ratio measurements to determine the concentration of a minor element relative to the concentration of a major element known from a KED measurement. The simultaneous determination of the U and Pu concentration in reprocessing input solutions, with a typical U/Pu-ratio of $\cong 100$, represents an important example for such an application.

Hybrid K-edge/XRF densitometer

This instrument combines the two techniques and is applied to the measurement of input solutions in reprocessing plants having typical U concentrations of 150-250 g/l and Pu concentrations of 1-3 g/l [2]. In this case U is measured by K-edge and the Pu/U ratio by XRF.

COMPUCEA

The name stands for COMBined Product Uranium Concentration and Enrichment Assay. This is a combined instrument composed of a transportable K-edge densitometer for uranium concentration and a gamma spectrometer (a well HPGe detector) for uranium enrichment [3]. It is typically used for uranium solutions and products from LEU fabrication plants to analyse uranium oxide powders or pellets



after dissolution in nitric acid. The main difference with respect to the classical K-edge is that the X-ray generator is replaced by two small radioactive sources producing photons with energy just below and above the uranium K energy.

COMPUCEA 2nd generation

It is an evolution of the instrument described above with increased portability. The two sources are replaced by a small X-ray generator of low energy, that allows to work on the uranium L-edge energy range. At this low energy the HPGe detector must be replaced by a silicon gamma detector. Also the enrichment spectrometer uses a gamma detector (NaI or LaBr₃) not requiring liquid nitrogen cooling that can be operated at room temperature.

2.3. Performance Values

Performance values for the determination of the uranium and plutonium volume concentration in liquid samples by means of KED and XRF are listed in Table 1. The main component dominating the random uncertainty is counting statistics, whereas short and long-term instrument variability and the uncertainties associated with reference solutions used for calibration represent the major error sources contributing to the systematic uncertainty. The application of strict procedures for measurement control and assurance are vital to keep the systematic uncertainty at the quoted level.

3. Other fields of application

XRF is widely used in material technology to measure chemical compositions and presence of impurities.

4. Additional information and useful links; references

- 1 A. Hastings, Jr. Smith, P. A. Russo, in *Passive Nondestructive Assay of Nuclear Materials*, chapter 9, NUREG/CR-5550, LA-UR-90-732 (1991).
- 2 H. Ottmar, H. Eberle, "The Hybrid K-Edge/K-XRF Densitometer: Principles-Design-Performance", Report KfK 4590 (1991).
- 3 P. Matussek, I. Michel-Piper, H. Ottmar, "A Compact K-Edge Densitometer for Uranium", Proc. 13th Annual ESARDA Symp. on Safeguards and Nuclear Material Management, Avignon, France, 14-16 May, 1991, EUR 13686 EN (1991) 329.

Web sites:

<http://www.canberra.com/products/760.asp>

http://www.canberra.com/pdf/Products/Systems_pdf/hybridk.pdf

Table 1: Performance values for volume concentration in liquid samples from KED/XRF measurements.

Type of Sample	Technique	Measurand	Counting Time (s)	Statistical error (%)	Systematic error (%)	Range of application
U-nitrate	KED	U-conc.	2000	0.2	0.15	> 100 g/l
U-nitrate	COMPUCEA	U-conc.	2000	0.2	0.15	> 100 g/l
U-nitrate	XRF	U-conc.	2000	0.5-0.2	1	1-50 g/l
Pu-nitrate	KED	Pu-conc.	2000	0.2	0.15	> 100 g/l
Pu-nitrate	XRF	Pu-conc.	2000	0.5-0.2	1	1-50 g/l
Reproc. input solution	HKED	U-conc.	2000	0.2	0.15	150-250 g/l
		Pu-conc.	3600	0.6	0.3	1-2 g/l

Radiation Monitoring Techniques for Monitoring the Movement of Discharged Fuel

1. Introduction

Radiation monitoring techniques are often used in safeguards to identify nuclear material. In particular, Non-Destructive Assay (NDA) techniques are used to characterize a material through its radioactive emissions. Radiation monitoring can also be used to monitor the movement of irradiated material, making the technique also a Containment/Surveillance tool. Radiation monitoring is used in this way in a number of situations; in particular it is used in the monitoring of CANDU ("CANada Deuterium Uranium) reactors for safeguards purposes. The CANDU design, with particular reference to the CANDU-6, is used here to provide examples of how radiation monitoring may be applied to monitor the movement of irradiated material.

2. Design overview

2.1 On Load Reactors

On Load Reactors (OLRs) such as the CANDU load new fuel and discharge spent fuel while operating at full power. Proper management of the fuel held in the core ensures even burn-up of the fuel bundles and efficient operation. Typically, there are daily movements of fresh fuel into the reactor and spent fuel out of the reactor. Non-OLR reactors are fully charged with fresh fuel, run as long as is efficient and then the contents of the whole core are changed. The latter operation is relatively easy for an IAEA inspector to monitor because the core can be sealed and the re-fueling occurs over a short period of time. The continuous fueling of the OLR reactor, with its daily discharges, needs continuous monitoring. For CANDU reactors such systems have been in



Figure 1–Typical CANDU fuel bundle

operation for some time and are now able to transmit their data to the IAEA on a daily basis.

2.2 CANDU Fueling

A single bundle of CANDU fuel is approximately 0.5 meters long. Figure 1 shows a typical CANDU fuel bundle.

Fuel is normally loaded into a fuel channel and discharged from it as pairs of bundles.

Two distinct fueling methods are in use:

- The latch method.
 - Irradiated fuel is inserted and withdrawn from a fueling channel on carriers, one pair of bundles at a time.
- The separator method.
 - The entire contents of a channel are pushed as a string towards the receiving fueling machine as new fuel is inserted

Both methods use a pair of fueling machines that operate simultaneously at each end of the same fueling channel. The method of fueling is important when reviewing CDM data.

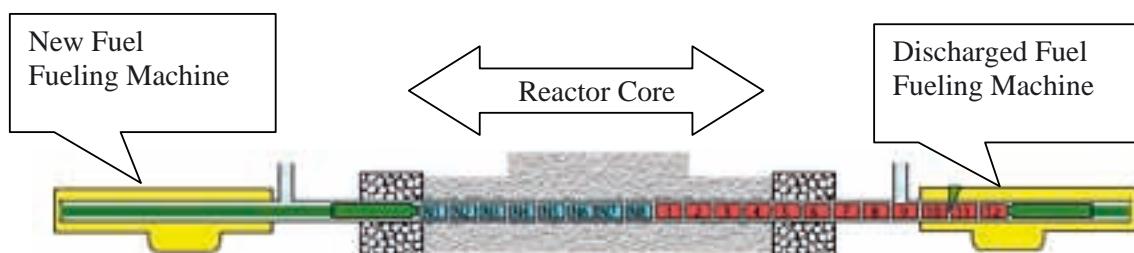


Figure 2–Fueling using the separator method (e.g. CANDU 6). Bundles 11 and 12 are being “separated” prior to storage in the fueling machine magazine.

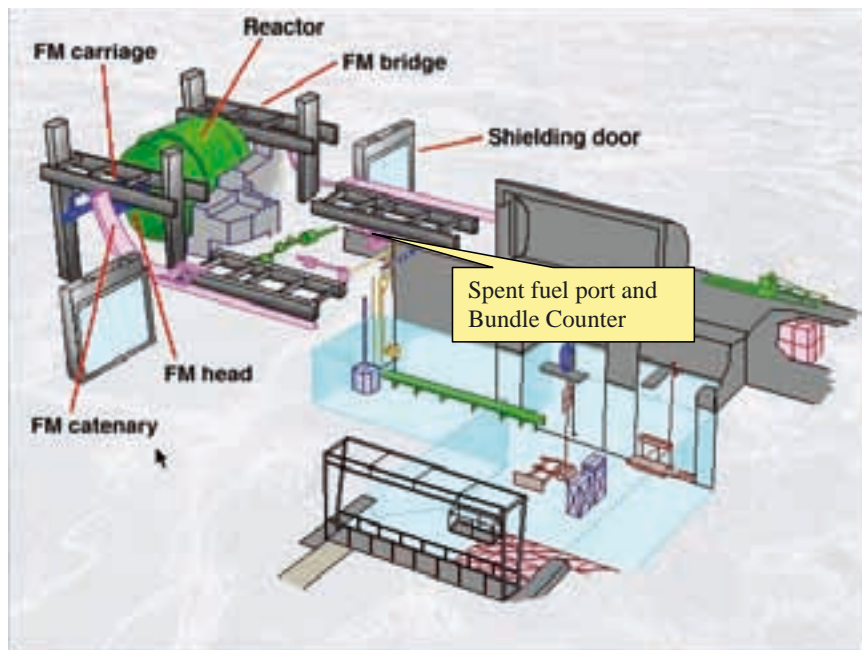


Figure 3–The discharged fuel path showing (4 detector) Bundle Counter location (CANDU-6)

All CANDU 6 reactors use the separator method. Figure 2 below shows one stage during the fueling of a single channel using the separator method.

New fuel (N1-N8) is being pushed into the core from the Fueling Machine on left hand side, one pair of bundles at a time. Irradiated fuel is being pushed out of the fuel channel at the right hand side and loaded into the Fueling Machine on the discharge side. Each pair of discharged fuel bundles is separated from the string and loaded into the fueling machine magazine, one pair at a time.

Figure 3 below illustrates the path that spent fuel follows from a CANDU-6 reactor to the irradiated fuel bay. The Fueling Machine (FM) on the discharge side of the reactor collects spent fuel and traverses to the spent fuel port location where the spent fuel is discharged to the bay, passing the Bundle Counter detectors on the way. Figure 4 provides a plan view of the Bundle Counter locations (BC1 and BC2).

3. Radiation monitoring and the CANDU 6

3.1 Principal Roles

There are three principal roles for radiation monitoring in the case of the CANDU reactors:

- Core Discharge Monitor (CDM)
 - to monitor the discharge of any spent fuel from the reactor core to the spent fuel discharge port
- Bundle Counter
 - to monitor the movement of spent fuel from the spent fuel discharge port to the spent fuel bay

- Yes/No monitor
 - to ensure that no spent fuel moves along a potential diversion path.

The associated detector configurations are as follows:

Role	Type of detectors	Collimation	Configuration of detectors
Core Discharge Monitor (CDM)	Gamma and Neutron	No	<ul style="list-style-type: none"> - Wall mount, 4 locations, 2 inline with each face of the reactor - camera (floor) mount, 2 locations, one on each side of the reactor.
Bundle Counters	Gamma	Yes	4, 2 and 1 detector configurations in use
Yes/No monitors	Gamma	No	Single detectors

The VIFM (VXI Irradiated Fuel Monitor) system handles the collection of data from these systems and its analysis. Radiation data and fully analyzed info (i.e. bundle counts) can be accessed remotely by the IAEA.

3.2 Core Discharge Monitor (CDM)

To implement a CDM, neutron and gamma detectors need to be installed within the reactor containment. Figure 4 below shows the typical deployment of detectors at a CANDU 6 facility. In this topside, cutaway view, the reactor calandria appears at the right and the spent fuel ponds are at the left. A facility would have either camera or wall mount CDM detectors – not both as shown in this figure. The camera mount configuration uses floor locations (C1/CDMA, C2/CDMC) that were originally occupied by cameras; detectors installed in this way may be

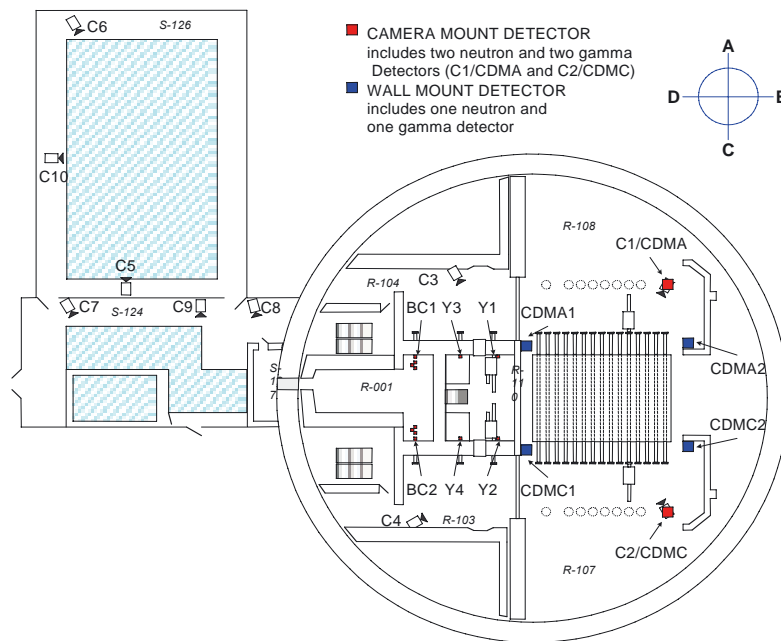


Figure 4—Options for detectors in a typical CANDU-6

exchanged through the reactor vault floor penetration while the reactor is on power. Using the wall mount configuration, detectors are mounted almost inline with the face of the reactor. With this configuration there is no possibility of changing detectors while the reactor is on power, so additional detectors are incorporated to provide redundancy.

The floor mount configuration also provides spatial diversity to address any temporary blockage that may occur due to the fueling machine location. The neutron detectors provide an immediate indication of irradiated fuel being taken from the core. The gamma radiation, although more persistent, is effected by the shielding, which varies according to the bundle location and in particular is influenced by the rotation of the fueling machine magazine. Gamma signals are evident when there is any movement of irradiated fuel; however since they are strongly influenced by fueling machine rotation and movement, they are generally more difficult to interpret. In the case of discharges from an off-power reactor, the gamma trace becomes more important.

CANDU fueling is carried out under automated control; the movements and corresponding CDM detector signals are repetitive and predictable; a detailed study has been carried out by Budzinski and Böck [3]. As a result, automated analysis can easily handle the majority of discharge activities with confidence. The VIFM system which is responsible for data collection on-site automatically carries out the analysis of the CDM data on completion of the fueling operation. Summary files

are generated which contain information on the number of bundles discharged and the time they were discharged. In the case of any irregularity (low burn-up fuel bundle or fueling machine problem), the automatic algorithm may fail and the discharge will be identified as anomalous. It is understood that this is uncommon and if it does occur can usually be resolved quickly by manual review of the data.

3.2.1 CDM neutron signature when using the separator method (8-bundle push)

In the case of the separator method, the fueling method used at CANDU 6 stations, there are extra peaks that need explanation. For instance, when four bundle pairs are discharged from a CANDU 6, there are two “extra” peaks. The red trace in the Figure 5 below shows a typical neutron trace during the discharge of eight bundles.

In general, the neutron trace has two components:

- A prompt, but quickly decaying pulse generated when any new irradiated material is exposed outside the reactor shielding
- A base level that accumulates (and decays more slowly) as spent fuel is added to the de-fueling machine’s magazine

3.3 Bundle Counters

The CDM detects every irradiated fuel bundle that emerges from the core. Bundle Counters are used to monitor the movement of irradiated fuel as it travels to the irradiated fuel bay. Figure 4 shows potential detector locations for Bundle Counter detectors (BC1, BC2).

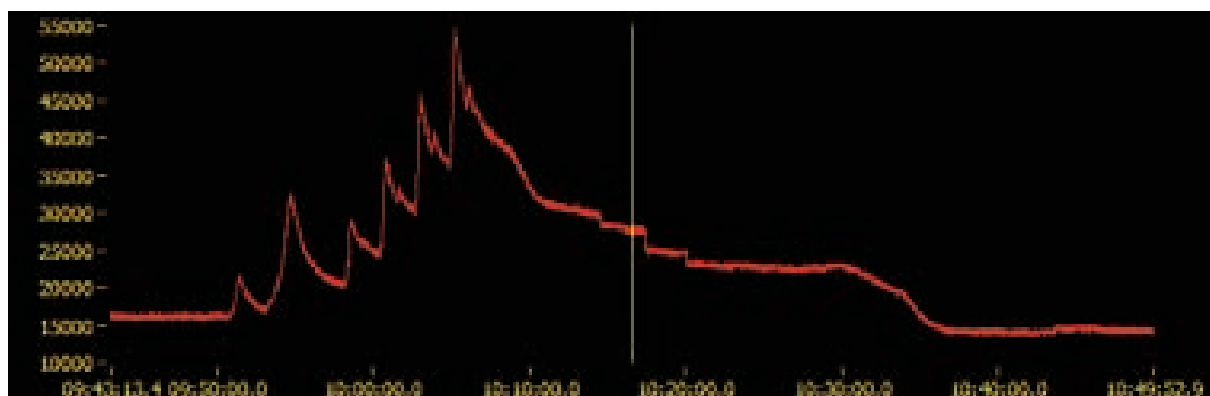


Figure 5–Typical CDM (neutron) trace for a CANDU 6 discharge of eight bundles.

A Bundle Counter needs to sense both number and direction of motion of bundles being discharged; to do this up to four detectors may be used. The Bundle Counter detectors are collimated to allow precise observation of the bundle movement; bundles can be moving quite quickly and in pairs. Higher sampling rates are often required for a Bundle Counter than would be required for a CDM.

Figure 6 shows a partial cutaway view of a 4-detector Bundle Counter installation on a CANDU 6 spent fuel elevator. The spent fuel port, where the fuelling machine attaches to unload the spent fuel held in its magazine, is on the right.

Figure 7 illustrates how the signatures are generated by the bundles passing the 4 detectors.

In a normal discharge of a pair of bundles through the spent fuel port, the bundles are pushed (horizontally) past the first 3 detectors. The elevator

then lowers the fuel to the spent fuel bay, passing detector 4 end-on in their descent.

A typical signature produced by a 4-detector Bundle Counter may look like this:

The four pulses shown correspond to detectors 1-2-3-4. The order of the pulses indicates that this was a forward or “to-bay” transfer.

The overall amplitudes of the signals from the detectors are not as critical as their form. Because detector 4 views the end of the bundle rather than the side, it generates a narrower pulse. The small V-shaped notches that appear in the plateaus of pulses 1 and 2 are the reduced gamma count produced as the gap between the two bundles passes the detectors.

Algorithms have been developed to automatically analyze the data from Bundle Counters and provide the number of transfers and the direction of the transfer with a high degree of confidence. Occasionally, a low burn up bundle may cause the algorithm to flag an “anomalous transfer”. Such events can easily be resolved through a manual review of the radiation data.

The number of transfers detected by the Bundle Counter should match the number discharged by

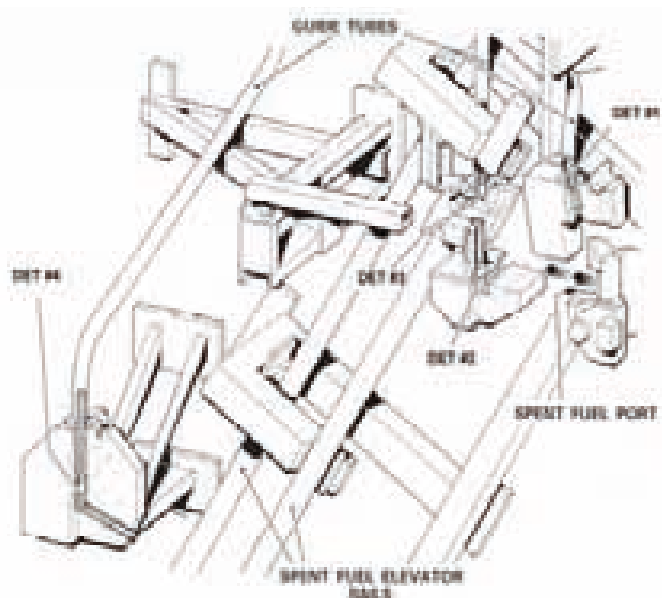


Figure 6- Mechanical design of a 4 detector Bundle Counter

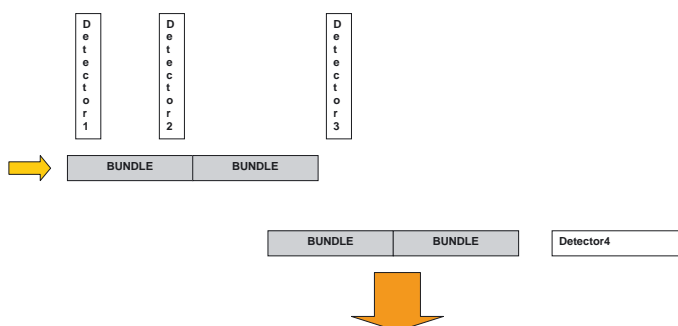


Figure 7–4 Detector Bundle Counter schematic

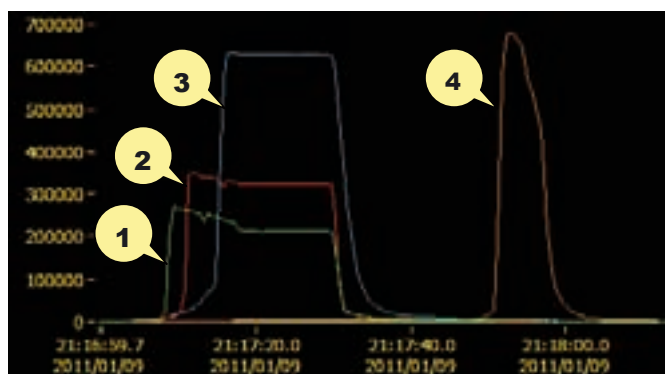


Figure 7—Response provided by 4 detector Bundle Counter

the reactor and recorded by the CDM as well as those directly reported by the facility.

3.4 Yes/No Monitors

Figure 4 shows how Yes/No monitors may be deployed (Y1, Y2, Y3 and Y4) at a CANDU 6. The role of these is simple, to report if any irradiated material passes within their fields of view. A thorough analysis of the design information will reveal any potential diversion paths and identify key points that may need monitoring with a Yes/No monitor. An event detected by a Yes/No monitor may be an opportunity to trigger surveillance cameras to provide additional information. The algorithm used to analyze Yes/No Monitor data is fairly simple, typically the same as a single detector Bundle Counter. Normally, Yes/No Monitors should expect to report no events. As in all unattended remote monitoring, raw data is recorded continuously, so that any period of concern can be re-examined later.

4. Conclusion

Three distinct roles for radiation monitoring have illustrated using the CANDU 6 as an example:

- Detection and counting of irradiated fuel items leaving the reactor
- Counting of irradiated fuel bundles being transferred to the spent fuel bay
- Use of strategically located detectors to confirm that no irradiated material is removed from the contained area via a possible diversion path

Used together, these measures provide an accurate count of fuel discharged and assurance that all of it has been delivered to the spent fuel bay.

Because of the extensive wiring that may be required for detectors, radiation monitoring techniques are expensive to install. Before any decisions can be made on implementing any solution depending on

radiation monitoring, an intensive review of the facility design must be carried out. This review needs to examine the path taken by discharged fuel and any potential diversion paths. Based on this review, detectors can be placed strategically to ensure diversion cannot take place without detection. Video surveillance may be used to complement radiation sensors; in particular radiation sensors may be configured to trigger a shorter picture taking interval to ensure that an episode of interest is captured reliably.

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JRC Ultrasonic seals

1. Introduction

Within the framework of Nuclear Safeguards, there is a demand for a robust and durable system of seals for the monitoring, identification and verification, over a period of several years, of containers used for under-water storage of fissile materials to be reprocessed.

There is also a demand for an identification system, for example for nuclear transportation casks, or for other movable structures of strategic value (containers, weapons, explosives, etc.) which have to be supervised or indexed.

Ultrasonic seals can respond to such needs. By its own nature, the seal itself can last for several decades without losing information. It is purely passive; all the complexity is in the reading system that can be easily maintained or upgraded.

The discussion in this technical sheet deals with JRC/SILab ultrasonic seals only. Ultrasonic seals built according to other methods would have different characteristics.

Fig. 1: Principle of ultrasonic measurements

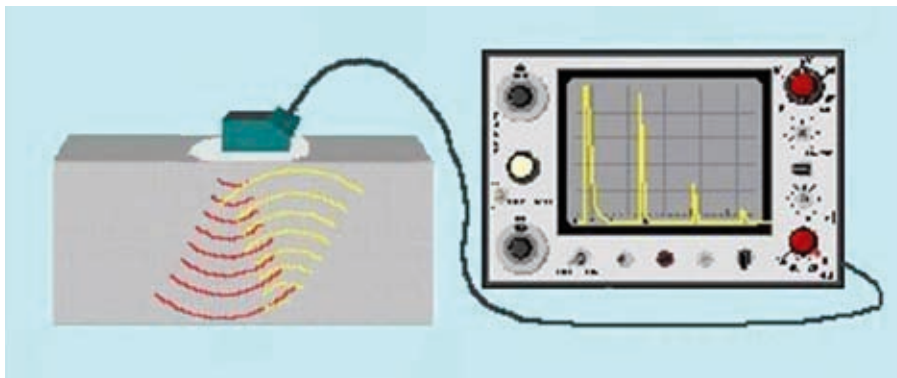


Fig. 2: Discs used for the identity and brazed together



2. Basic concepts on ultrasonic measurements

A typical system includes a pulser/receiver, a transducer, and an analysis device. The pulser/receiver is an electronic device that produces high voltage electrical pulses. Driven by the pulser, the transducer generates high frequency ultrasonic energy. The sound energy propagates through the materials and when there is a discontinuity in the wave path, a part of the energy is reflected by the surface. The reflected wave signal is transformed into an electrical signal by the transducer and analyzed by the analysis device. Signal travel time can be directly related to the distance that the signal has traveled. Information about the reflector location, its size and orientation, and other features can also be gained from the signal.

3. Basic concepts of SILab ultrasonic seals

A seal has to provide evidence of any access to the content of the sealed item, whether authorized or unauthorized. It is usually attached to a closed container to the end of ensuring that any opening will be indicated.

The internal structure of the ultrasonic seal comprises a unique (irreproducible) identity and a frangible element (integrity) which breaks when an attempt is made to remove the seal from the sealed item.

The reading device consists of a transducer which generates an ultrasonic signal and senses the reflected signal. The transducer rotates above the sealing bolt recording the ultrasonic echoes reflected over a complete revolution.

The seal is designed to replace one of the standard bolts/nuts of the container lid, or to be installed on

ad-hoc devices. It is so possible to verify, when inspected, whether or not they have been unscrewed or removed for opening.

When the seal is used in replacement of a bolt or a nut, the body of the seal has the same mechanical properties as a standard bolt/nut (thread and applied torque).

4. Realisation of the seals

The identification feature consists in an assembly of several discs randomly stamped (Fig. 2 left), which are brazed together to form a univocal identity (Fig. 2 right). The quantity of brazing paste used is not enough to fill all the holes and the diffusion of the brazing paste inside the holes cannot be predicted.

The integrity feature consists in a thin metal rod with a weak point which breaks when torsion or traction is applied to it (Fig. 3).



Fig. 3: Integrity feature

The identity and integrity components are then brazed together to give the core of the ultrasonic seals. The core of the ultrasonic seal (Fig. 4) is a cylindrical assembly containing its unique identity and the integrity feature which breaks when opened. This assembly is radiation resistant and particularly reliable even under very harsh environmental conditions.



Fig. 5: Custom seals designs



Fig. 4: Core of SiLab ultrasonic seals

This core is then welded onto the top of the seal. The bodies of the seals are designed according to their application.

Each application of ultrasonic seals requires an adaptation of the mechanical interface. Therefore, there are seal designs with bolt characteristics, with nut characteristics, and seals that are clipped on the item. These adaptations do not affect the ultrasonic core, but only the way the seal is attached to the sealed item.

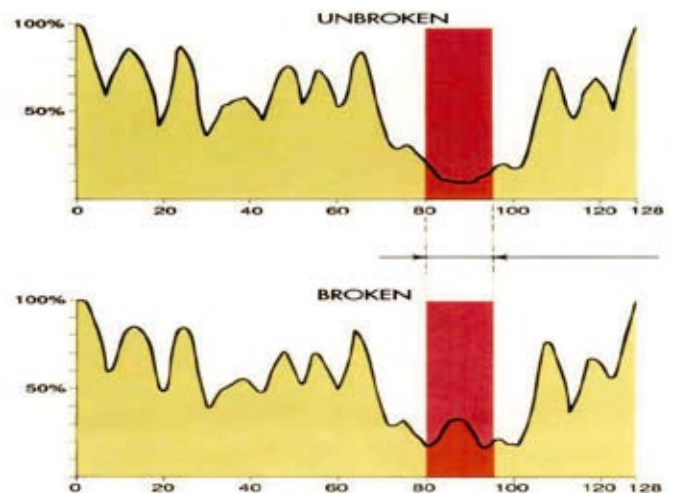


Fig. 7: Difference of readings between an unbroken and a broken seal

5. The reading device

Seal identity and integrity are monitored through the metal by using an ultrasonic reading head which consists of a transducer generating a high frequency ultrasonic pulse. In order to obtain a complete fingerprint of each seal, the transducer is rotated above the seal, and the echo is recorded for each position of the transducer. Figure 6 shows the intensity of the echo as a function of the angular position of the transducer. The X axis displays a complete revolution (360°).



Fig. 6: Fingerprint of a seal

During inspections, after a complete reading, a mathematical correlation with the reference reading is calculated. The reference reading is a previous reading made by an authorized safeguards inspector. The seal is considered as "Identified", if the correlation between the two readings is higher than 0.93. Then, an analysis of the integrity area (the red area in Fig. 7) will determine the "Broken" or "Unbroken" status.

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For more information:

<http://silab.jrc.it>

http://en.wikipedia.org/wiki/Ultrasonic_inspection

http://www.ndt-ed.org/EducationResources/CommunityCollege/Ultrasonics/cc_ut_index.htm

2007 ESARDA Course Essays

Introduction to the publication of two selected essays of the students from the 2007 ESARDA Course.

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Chair of the ESARDA Training and Knowledge Management Working Group

The ESARDA WG TKM has organised now since 4 years an academic course module on nuclear safeguards and non-proliferation with a full 5-days program of lectures by experts in the field of nuclear safeguards, visits to safeguards laboratories and some classroom exercises. This course is providing the in the European curriculum for Nuclear Engineering. It was last held from 5 to 9 March 2007 and will be organized in 2008 from April 14 to 18 again in Ispra.

This project is in line with the movement of establishing a European curriculum for Nuclear Engineering and Nuclear Security. Teaching in the nuclear field is indeed strongly influenced by national history so the objective of the course is to provide reviewed/approved material in Nuclear Safeguards and Non-Proliferation matters at the European and international level.

This compact course is open to Master Degree students, in particular Nuclear Engineering students, but also International Relations/ Law Students and to young professionals.

It aims at complementing nuclear engineering studies by including nuclear safeguards and non-proliferation in the academic curriculum. The basic aim of the course is to stimulate students' interests in these areas, demonstrating that the nuclear field is at the same time restricted and supported by a full set of regulations.

The course addresses aspects of the efforts to create a global nuclear non-proliferation system and how this system works in practice: e.g. the Non-Proliferation Treaty, safeguards technology, and export control. Also regional settings, such as Euratom Treaty, are presented and discussed. The course deals in particular with technical aspects and application of safeguards and non-proliferation; i.e. how to implement the safeguards principles and

methodology within the different nuclear facilities and e.g. how to increase the chances to discover clandestine nuclear activities. It thus provides an overview on inspections techniques, ranging from neutron/ gamma detectors, to design information verification, to environmental sampling, nuclear country profiling etc.

In the 2007 session, all 61 students were encouraged to make an essay on a given topic, with which they can apply for the recognition of 3 credits that the Belgian (as part of the European) Nuclear Higher Education Network gave to it (equivalent to 1/20 part of one academic year programme). The student award for the 3 credits course is based on an evaluation by a panel of 5 experts in nuclear safeguards and non-proliferation and is coordinated by the ESARDA WG Training & Knowledge Management. The two best papers were selected for publication in this ESARDA bulletin. They are not peer reviewed but the students have implemented the comments of the evaluation panel. These essays demonstrate the understanding by the students and give an indication on the level of depth by the lectures in this one week course.

Final Essay after ESARDA course on nuclear Safeguards and non-proliferation

Methods for the detection of undeclared plutonium production facilities

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Abstract:

Among the safeguarding practices aimed at the detection of undeclared nuclear activities, the importance of environmental sampling and nuclear forensics has grown in the last decades. In fact, the production of raw materials for nuclear weapons can be pursued either by processes to produce very highly enriched (weapon-grade) Uranium or by chemical separation of plutonium from reactor's spent fuel, in a hidden branching of an officially non-military nuclear fuel cycle. Both these processes will result in the release to the environment of some characteristic materials, which can be found in the liquid and gaseous effluents or concentrated in sediments, soils, vegetation, livestock and biota.

In this paper, some environmental sampling based techniques aimed at supplying evidence of plutonium production facilities are discussed, with particular attention to wide area atmospheric monitoring of Kr-85 and on environmental signatures in the environs just around a reprocessing plant.

Keywords: Reprocessing; Kr-85; I-129; plutonium

Introduction

The detection of undeclared nuclear activities has become a fundamental part of safeguarding practices after the 1990s, when the discovery by IAEA of the Iraq clandestine nuclear program evidenced the possibility of undeclared proliferant activities in a state that signed the NPT. In order to prevent the risks related to hidden activities aimed at the production of nuclear materials, the additional protocol INFCIRC/540 foresees environmental controls for the detection of tell-tale traces in the environment and in particular environmental signatures of the physico-chemical processes related to nuclear activities. In particular, in the implementation of the so-called complementary

access under article 5 of the aforementioned protocol, IAEA inspectors shall have right to access "Any location specified by the Agency [...] to carry out location-specific environmental sampling, provided that if the State concerned is unable to provide such access, that State shall make every reasonable effort to satisfy Agency requirements, without delay, at adjacent locations or through other means" [1]. The Article 9 of the protocol, on the other hand, provides the possibility to carry out wide-area environmental sampling, although it states that "The Agency shall not seek such access until the use of wide-area environmental sampling and the procedural arrangements therefore have been approved by the Board and following consultations between the Agency and the state concerned".

To summarize, the introduction in the INFCIRC/540 is of paramount importance from the point of view of environmental sampling as it first puts a legal basis for it, whereas in the NPT full-scope safeguards as stated in the INFCIRC/153 there is no explicit provision in that direction. [2]

A potential proliferant state seeks to have a technological infrastructure which consists of: a) weapon technology; b) warhead carrier (missile) technology; c) availability of weapon grade material. Of course, the lack of any of the parts, and in particular part c), impedes the proliferation, even if this doesn't mean the reduction of the proliferation threat. The availability of weapon-grade nuclear material can be pursued either by the purchase of the necessary amount of almost ready-to-use material on the nuclear smuggling market, which is an option not free from risks, arising from border controls and from the involvement of criminal networks, or by in-house production of weapon-grade material from non-weapon nuclear materials, diverted from a civil fuel cycle or purchased on the black market.

The production of nuclear weapon-grade material may then follow basically two approaches: on the one hand there may be set up a clandestine uranium enrichment plant, while on the other hand there may be production of plutonium by chemical separation from reactor's spent fuel in an undeclared reprocessing facility. Both these processes result in the production of characteristic materials, some of which will be released in the environs, therefore accurate environmental sampling may allow their detection. In this short essay, the methods for detecting Pu breeding through environmental controls will be discussed, by describing the types of characteristic materials which are most likely to be released and the environmental matrices where they are likely to be accumulated, together with field examples taken from scientific literature.

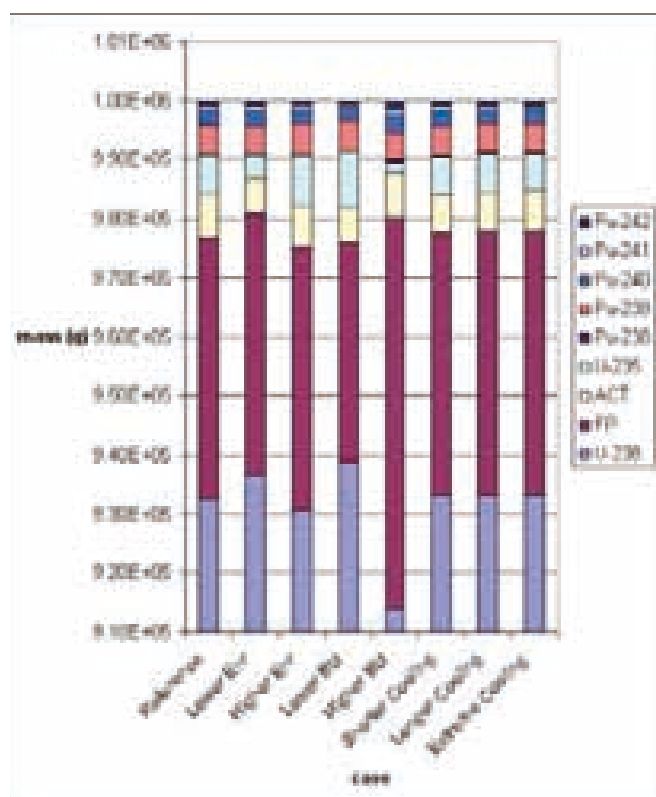


Figure 1 Isotopic composition (FP: Fission Products, ACT: Actinides different from those individually mentioned) [3].

Nuclear Fuel Reprocessing and its environmental signatures

During reactor operation, the irradiated fuels is steadily changing its isotopic composition. In the case of U fuel, the ^{238}U , present in high percentage, will result in the build-up of plutonium isotopes by n-capture and beta-decay chains, whereas ^{235}U is fissioned producing another amount of fission products (FP) accumulated inside the fuel elements. This isotopic composition depends on the fuel element's residence time inside the reactor (fuel burn-up) and on its initial composition. In Fig. 1

some examples of this effect are displayed for different reactor types [4].

Fuel reprocessing is defined as the technological process aimed, on the one hand, at the recovery of the fissile and fertile materials which were not used in the reactor and, on the other hand, at the separation of uranium, plutonium and other transuranium elements which are produced in the reactor. Normally this technique involves the chopping of the spent fuel assemblies, the removal of the cladding and the dissolution of the pellet in nitric acid. Tributylphosphate (TBP) is then added to this solution so that U and Pu can be separated chemically by solvent extraction. During this process, and especially during the chopping phase, some volatile radionuclides are released, passing through various types of filters and reactors to trap most of the fission and activation products.

Nevertheless, some of these will be emitted from the plant, including ^{85}Kr , ^3H , ^{131}I (present only in the case of fuel elements not left in the pond for a time long enough to allow the complete decay, i.e. $t > 1$ yr), ^{129}I , ^{99}Tc , ^{14}C , ^3He or in some cases particulate isotopes such as ^{103}Ru , ^{106}Ru , ^{137}Cs , ^{141}Ce , ^{144}Ce and ^{90}Sr [5] (see Tab. 1).

Table 1 – Half-life and natural abundance of nuclides potentially released by reprocessing plants (from open source internet sites).

Isotope	Half-life	Natural abundance
^3H	12.33y	-
^3He	Stable	$1.37 \cdot 10^{-4}$
^{14}C	5730y	$\sim 10^{-12}$
^{85}Kr	10.752 y	-
^{90}Sr	28.79y	-
^{99}Tc	$2.111 \cdot 10^5$ y	-
^{103}Ru	39.26d	-
^{106}Ru	373.59 d	-
^{129}I	$1.57 \cdot 10^7$	$3.17 \cdot 10^{-13}$
^{131}I	8.02 d	-
^{137}Cs	30.07 y	-
^{141}Ce	32.501 d	-
^{144}Ce	284.893 d	-

Location-specific environmental sampling signatures.

Among the aforementioned nuclides, ^{129}I and ^3H seem to be the most promising tracers for location-specific environmental sampling.

Part of the radioiodine is released to the atmosphere during dissolution process, while additional release

comes from elution of the sorption beds used for its trapping. Although ^{129}I is naturally formed by spontaneous fission of ^{238}U , its concentration at the earth's surface, in vegetation and in waters is very low, therefore its measurement in environmental matrices such as animal thyroids, air rain, soils and biota can be a good indicator of ongoing reprocessing activities. To have a quantitative idea of the capabilities of ^{129}I as tracer of reprocessing activities we can refer to Moran *et al.* [16], where most of the scientific work on ^{129}I as environmental sample for nuclear safeguards is reviewed. As an example we can cite that, according to literature, $^{129}\text{I}/^{127}\text{I}$ ratios measured in epiphytes within 60 km of the Sellafield site are between 15 and 6693×10^{-8} , 2-4 orders of magnitude higher than ratios measured in Germany and other parts of Europe.

Another indicator of fuel reprocessing plants is the presence of a tritium plume in underground waters, coming from the huge amounts of waters used in the process itself and in the rinsing of the reprocessing equipments or the washing of contaminated areas within the reprocessing cells. Collection and analysis of water samples for tritium detection can therefore provide indication of plutonium production activities at a suspect site.

In any case, the effectiveness of the use of these environmental indicators is thwarted by the possibility to collect only a limited quantity of samples of water or other environmental matrices by the inspectors themselves, often restricted to a few samples only, which prevents a satisfactory sampling strategy. Moreover, location-specific environmental sampling has the negative drawbacks of being restricted to samples (swipes, filters, water containers...) taken at the locations that are anyway routinely visited by inspectors, then it is not suitable to detect completely unknown activities.

^{85}Kr as environmental signature for wide area detection of reprocessing activities

Most of the limits of the location-specific sampling can be overcome by a wide-area detection sampling strategy. Studies as [6] and [7] have highlighted the potential of ^{85}Kr measuring as a the best wide area indicator for plutonium separation activities. ^{85}Kr is a fission product that is generated in the fuel elements of nuclear fission reactors together with plutonium. Being a noble gas, then chemically inert, and with a 10.7 year half-life, it can undergo long range transport and thus be detected at considerable distances from its source. Moreover, it is artificial, being produced only in U nuclear fission reactors (Typically 3.5 g/tU for PWR reactors with 3.5% enriched U fuel [8]), then its background concentration

is very low ($\sim 1 \text{ Bq m}^{-3}$ [6]). As shown in [15] production peaks of the La Hague reprocessing plant produce clear peaks in the airborne ^{85}Kr , up to 3.5 Bq m^{-3} even at remote monitoring stations located several hundreds of kilometres from the plant (Zugspitze). On [6] similar results are reported, highlighting that the minimum separation rates of weapon-grade plutonium that could have been detected at a distance of 130 km from the plant's stack are of 1 kg/week, to be compared against a significant quantity of 8 kg/week. Atmospheric modelling can then help in finding back trajectories yielding to an estimate to the region of origin of the ^{85}Kr : this may help in improving the data accuracy when applied to a network of sampling points.

Methods for the detection of environmental signatures from Pu separation activities

Analysis of ^{129}I

As mentioned in the previous paragraph, the measurement of ^{129}I in various environmental matrices is a well established method for the detection of undeclared nuclear fuel reprocessing activities. However, due to its quite long half life (15.7 million years), activity is normally too low for the measurement by direct counting using gamma spectrometry and the detection methods are not straightforward. The assessment of ^{129}I or of the $^{129}\text{I}/^{127}\text{I}$ ratio is usually carried out by Accelerator Mass Spectrometry (AMS), which has a high sensitivity for the abundance ratio $^{129}\text{I}/^{127}\text{I}$ down to 10^{-12} , or by Neutron Activation Analysis with Radiochemical separation (RNAA) which is able to detect abundance ratios of about 10^{-10} [9]. Recent studies have shown the development of an analytical set-up for the analysis of aqueous solutions and contaminated soil samples directly without sample preparation using ICP-MS with a hexapole collision cell (ICP-CC-QMS) [10]. An advanced review on different analytical techniques for ^{129}I determination was published by Schmidt *et al.* [11]. Typical samples analyzed by RNAA include animal thyroids, seaweed, algae, soils and plants, while AMS is the preferred method for ocean water samples, soil and plants from Southern Hemisphere (thus with lower isotopic ratios) and pre-nuclear samples [12]. It must be mentioned that AMS is able to detect only isotopic abundance ratios, therefore an independent assessment of total I is always necessary. A scheme of the analytical procedures for ^{129}I measurement is displayed in Fig. 2.

Airborne ^{85}Kr monitoring

Airborne concentrations of ^{85}Kr represent the most suitable tracer of plutonium separation activities even at long distances. The sampling and

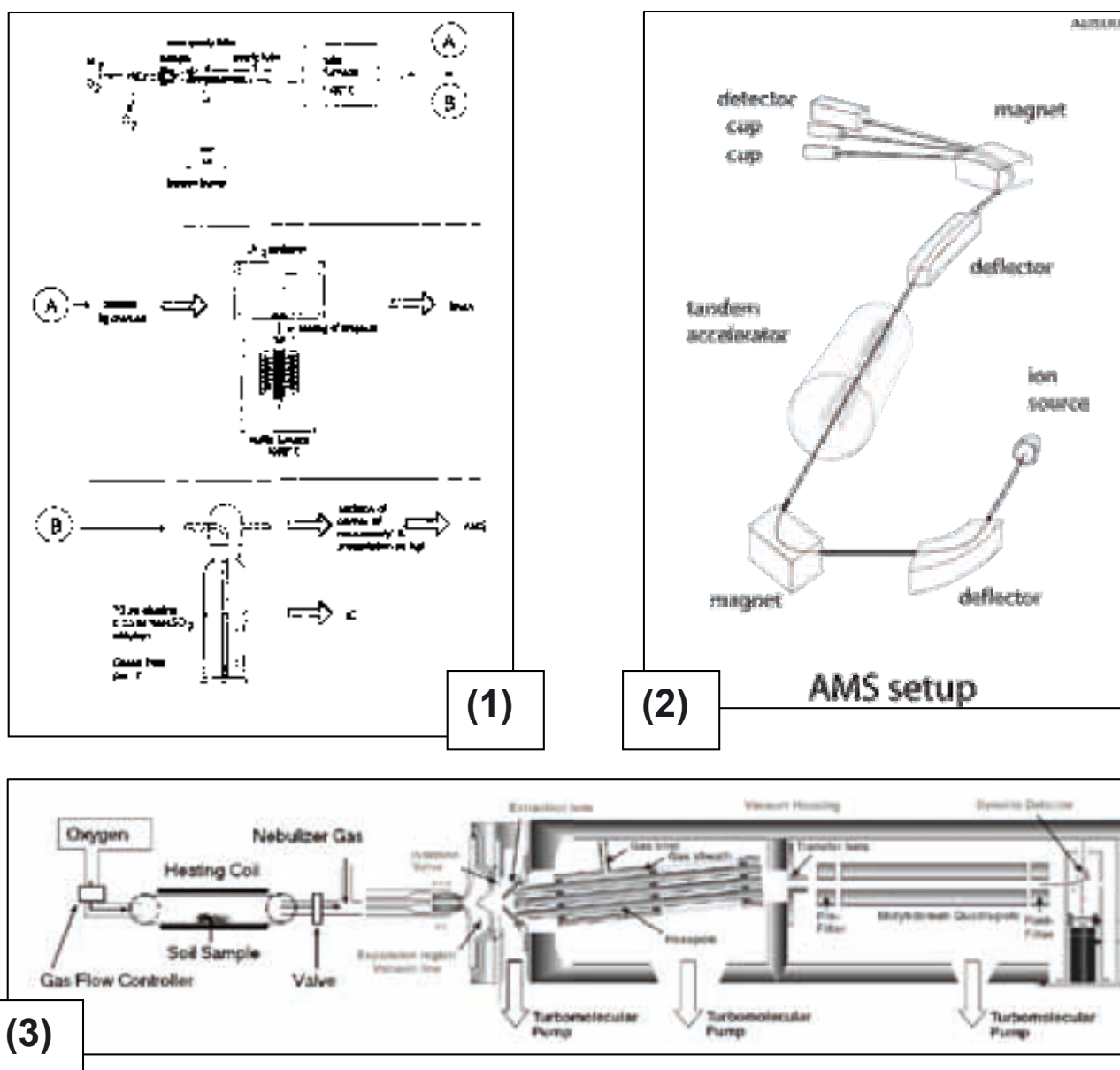


Figure 2 (1) Scheme of the separation of iodine from environmental samples for analysis by RNAA or AMS from [10], (2) scheme of AMS setup at Utrecht University (source: <http://www1.phys.uu.nl/ams/Method.htm>) and (3) schematic diagram of the ICP-CC-QMS with attached device for iodine introduction via the gas phase [9].

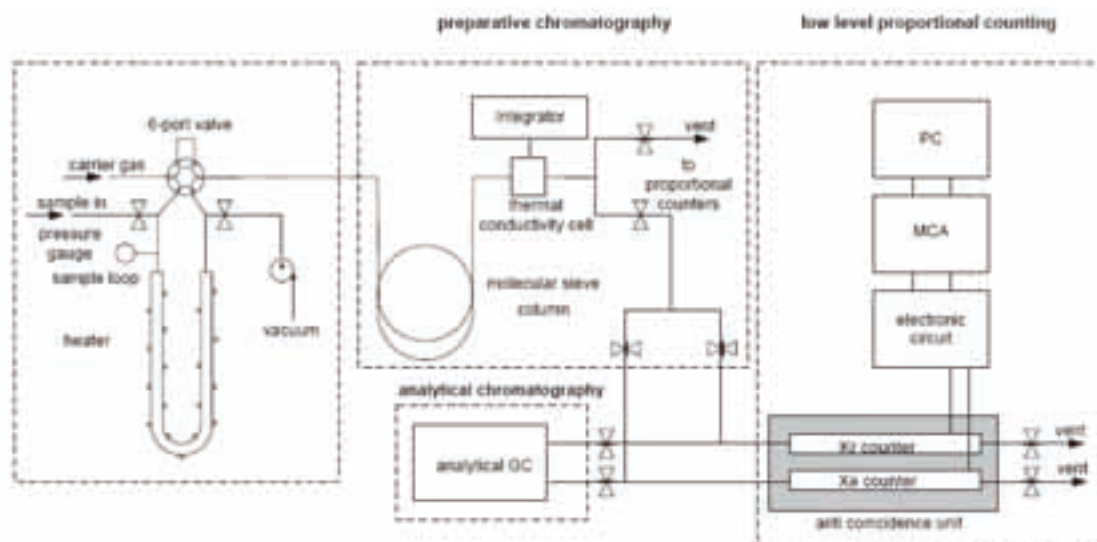


Figure 3 Scheme of the instrumentation for the analysis of ^{85}Kr and ^{133}Xe .

measurement methodology is described in [13] and reviewed in [14]. It basically consist of a forced flow of air through a liquid nitrogen cooled (77 K) trap in order to freeze atmospheric water vapor and CO₂. Afterwards noble gases, including the isotopes ⁸⁵Kr and ¹³³Xe, as well as ²²²Rn, are gathered onto an adsorber filter filled by activated charcoal. After the sampling period the filter is heated in order to release noble gases into an aluminum vessel, then purified and concentrated by Gas Chromatography and finally the ⁸⁵Kr is determined by β counting. A typical scheme of the measurement setup is shown in Fig. 3 [15]. Measurement of this type are routinely carried out in as part of the Global Atmospheric Watch (GAW) program by the World Meteorological Organization. The coupling of these data with backward trajectories modelling can evidence the region of origin of the ⁸⁵Kr sources, thus establishing where possible undeclared reprocessing facilities can be located [15] [6].

Conclusions

The two main methods for detection of plutonium production facilities have been described. The first one is based on location specific sampling, is well established since the 1960s and is carried out by measurement of ¹²⁹I in environmental samples collected in the surroundings of a suspected site. The second one, more recently developed as wide-area detection method, is carried out by analysis of airborne ⁸⁵Kr. Recent works like [5] and [13] have evidenced the potential of the integration of ⁸⁵Kr monitoring with atmospheric modelling aimed at calculating back trajectories is very promising because it can lead to an effective wide area detection (therefore without need to access at specific "suspect" sites) of fuel reprocessing plants and consequently of undeclared plutonium production activities.

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Verification Challenges for Safeguarding Uranium Enrichment Plants

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1. Introduction

This article represents a brief overview on the problem of safeguarding uranium deposits in process lines and equipment at uranium enrichment plants and points out a strong necessity for revisiting questions concerning monitoring of special nuclear material hold up at isotope-separation facilities.

Uranium enrichment is considered to be one the most sensitive stage of the nuclear fuel cycle from the nonproliferation standpoint. Nowadays only two principal technologies have been used on a large commercial scale for enriching uranium: gaseous diffusion and gas centrifugation. The gas diffusion process requires thousands to tens of thousands of barrier/centrifuge stages to enrich commercially or militarily significant quantities of uranium. Gas centrifugation is more technically advantageous technique since it requires much smaller number of stages (tens in versus a thousand). Furthermore, one of the most important advantages to the gas centrifuge over the gas diffusion process is also that it requires 40 to 50 times less energy to achieve the same level of enrichment.

Centrifuges currently have decisively superior economics to other uranium enrichment technologies. They account for half of the world's enrichment capacity, and will account for all of it after France and the United States complete their current programs to replace their gaseous diffusion plants with centrifuge plants. Therefore, there is every reason for a country wishing to acquire an enrichment plant to choose centrifuge technology. The U.S.A, France, and China are gradually abandoning their gaseous diffusion plants and plan to replace them with centrifuge facilities. Capacities in the original countries-members of Urenco consortium are being expanded and additional countries, often without significant domestic nuclear programs (such as Brazil or Iran), are independently pursuing centrifuge development. Unfortunately, no alternative enrichment processes with more favorable non-proliferation characteristics have been seriously considered since the 1970s and, hence, no alternative technology can compete economically with the gas centrifuge today.

At an enrichment facility the material balance areas would most likely be the cascade itself and the rooms in which feed, product and tails are stored and handle (specified in the Facility attachment for a peculiar facility) [1, 19]. In spite of the fact that IAEA inspectors have full access to the cascade halls what is originally authorized within the framework of an IFCIRC/153-type and later under IFCIRC/540-type agreement (that is originally emerged from the discussion and analysis of the Hexapartite Safeguards Project which was aimed at safeguarding gas centrifuge enrichment facilities and convened in 1980 to 1983. Inspectors' activities outside of cascade halls are based on conventional safeguards practices, whereas inside of cascade room they are used to verify that no material beyond the declared enrichment level and no HEU is being produced. Inspectors access is authorized by the Limited Frequency Unannounced concept.), as well as more recently safeguards techniques have been extended by Environmental sampling (high precision trace analysis) and other safeguards procedures under the Additional protocol (additional surveillance in the facility and monitoring uranium flow and enrichment on a continuous basis) [6], there is still a challenge for safeguarding uranium enrichment plants that happens due to some technology peculiarities of gas centrifugation and uranium hexafluoride physical properties.

2. Proliferation concerns associated with gas centrifuge enrichment plants

From a nonproliferation perspective, gas centrifuge technology has two principal drawbacks in comparison with gaseous diffusion technology. Firstly, the number of stages is much smaller (tens in versus a thousand) and so the uranium moves through the cascade very quickly. Second, the inventory held up in a typical cascade is more than a thousand metric tons in a gaseous diffusion plant as compared to a few kilograms in a centrifuge plant. However, it doesn't necessarily mean that there is no necessity control this in-process inventory. Therefore centrifuge cascades, on the other hand, can relatively easily be made to produce higher enrichments-either by adjusting the feed

rates, by reintroducing higher enriched material into the feed, or by reconfiguring the cascade itself [18]. Since centrifuge-cascade equilibrium times are on the order of minutes to tens of minutes, such a change in enrichment levels could be accomplished much more rapidly than for gaseous diffusion plants, whose: equilibrium times are weeks to months [19]. Nowadays it is unlikely that operators of existing safeguarded centrifuge facilities would reconfigure or operate them clandestinely to produce HEU. Nevertheless, such a reconfiguration or modified operation is certainly possible and might even elude detection if them were a several-month period between safeguards inspections and if the alteration could somehow be made to look to the plant's containment and surveillance system like routine maintenance. Any such reconfiguration would require the collusion of many plant operators to keep it secret, however, providing a further deterrent. This makes possible a "breakout" scenario, where peaceful technology is quickly converted to weapon use. Moreover, clandestine centrifuge facilities are virtually impossible to detect with remote-sensing techniques. A centrifuge plant with a capacity to make HEU sufficient for a bomb or two per year could be small and indistinguishable from many other industrial buildings. Due to its low power consumption, there are no unusual thermal signatures as compared to other types of factories with comparable floor areas. Leakage of UF_6 to the atmosphere from centrifuge facilities is also minimal because the gas in the pipes is below atmospheric pressure. Air therefore leaks into the centrifuges rather than the UF_6 leaking out. This contrasts dramatically with the first uranium enrichment plants in the declared nuclear weapon states, which were gas-diffusion plants with huge inventories and power requirements.

3. Diversion scenarios at centrifuge enrichment facilities

According to the IAEA methodology, the term "hold-up" is defined as nuclear material deposits remaining after shutdown of a plant in and about process equipment, interconnecting piping, filters and adjacent work areas. For plants in operation, the hold-up is the amount of nuclear material contained in the process. It is also referred to as in-process inventory [2, 3]. The deposit formation happens due to some chemical properties of uranium hexafluoride. Chemically, UF_6 is a strongly reactive substance. Uranium hexafluoride does not react with oxygen, nitrogen, carbon dioxide, or dry air, but it does react with water. When UF_6 comes into contact with water,

such as water vapor in the air, the UF_6 and water react, forming corrosive hydrogen fluoride (HF) and a uranium-fluoride compound called uranyl fluoride (UO_2F_2). In practice the hexafluoride of uranium is the only chemical compound that has a large magnitude of vapor pressure at a room temperature [1,10], what makes conditional upon its outcome of reduction processes that result not only in loss of UF_6 but also in formation of solid-state uranium compounds that produce accumulations of nuclear material holdup and corrosion in the internal surfaces of facility process lines (UF_6 processing equipment (corrosion-resistant), specialized compressors/pumps/seals, diffusion barriers, large heat exchangers), pipes, tanks, ducts, drums, furnaces, plug barrier bank filters and other technological equipment.

Determining the location of material held up and its magnitude in process equipment is of utmost importance not only because of the high economic value of nuclear material and the need to ensure radiation safety and criticality safety but also it is necessary with a view to safeguarding against possible theft or diversion. While the nuclear material that is actually in hold-up may not be of particular concern with respect to nuclear proliferation and nuclear security, a plant's declaration of hold-up may be a way of concealing diversion of nuclear material. Overstating the amount of special nuclear material in the form hold-up can allow an operator to divert nuclear material, but when the hold-up of a facility can be precisely characterized and verified it assures that this possible proliferation path-way is entirely excluded.

The expected operator measurement uncertainty associated with closing a material balance is defined by the IAEA as 0,2 percent of the larger inventory throughout [3], for large facilities with high entire enrichment capacities according to this value the total magnitude of special nuclear material unaccounted for could be much more than it is required for a significant quantity. Thus because of the extensive the total hold up could be large by its distribution alone, even if deposit thicknesses are small, there is an urgent need in improving measurement treatment of SNM hold up.

The overstating nuclear material in hold-up opens at least two concealment strategies: diversion by biasing (overstating/understating weight of shipped/received UF_6 cylinder; overstating/understating purity of UF_6 ; overstating/understating isotopic assay of uranium) and diversion in MUF (Material Unaccounted For) [18]. A straightforward solution for the reduction of MUF in the form of uranium

hold-up is to check material balances at uranium enrichment plants more often, so that smaller quantities are involved [1]. However, quite aside from the inconveniences and expense of taking inventory by IAEA/EURATOM inspectors this often (it must be mentioned here that there were no real growth in the IAEA regular budget until 2004 following more than 15 years of “zero” growth and that also makes conditional upon why the IAEA seeks for rational economy of its resources; that is why, for instance, the conception of integrated safeguards was launched), it should be noted that the size of the hold-up in the cascade, and therefore its measurement error, does not depend on the time interval between inventories. This puts a limit on the accuracy which can be achieved in any material balance, no matter how short the time between balances.

4. Current verification challenges for safeguarding gas centrifuge enrichment plants

The technique for monitoring uranium holdup control in processing equipment is based on the registration of intrinsic gamma-radiation of uranium in the energy ranges chosen. Control of nuclear material holdup could be fulfilled by detecting of energy gamma-radiation of 185,72 keV peak of U^{235} (Infinite Thickness Approach). There are also a number of factors such as the mass/density of nuclear material deposits, enrichment magnitude, the weight fraction of uranium, geometry of the experiment, nuclear material and pipeline material self-attenuation factors, pipeline pressure which can play an important role when determining the cause and magnitude of mistakes and uncertainty (error treatment is all-important: according to the ESARDA Performance Values for Non-Destructive Assay (NDA) Techniques only systematic uncertainty can vary from 2 to 10 % depending on the actual measurement conditions, on the evaluation and measurement procedures used, and on the calibration standards available for calibration; the random uncertainty is ranging from 1,5 to 3% [9]), the significance of that for safeguarding purposes are to be clarified. Nevertheless, the measurement of SNM held up will be much more precise if the generalized geometry (GGH) assay method is employed as it allows correcting for the negative bias that arises from the systematic effects of both the geometric models and gamma-ray self-attenuation [8].

Determining the location of special nuclear material held up in process equipment is really complicated.

Even measuring the quantity of holdup is difficult and subject to a lot of uncertainties. A possible alternative method for obtaining some of the hold-up data required for periodic inventory is to estimate the hold-up by means of statistical modeling. This approach would begin with careful, controlled holdup measurement of a process operation under known conditions. The measured holdup would be modeled as a function of important variables. Then future holdup in this process operation could be estimated and predicted on the basis of the model. However it is only possible to make a general model/identify regions where holdup may be high (considerable to safeguards purposes: elbows, junctions, seams in pipes and ducts, regions of stagnant flow or with turbulent flow, with highly corrosive substances as in case of UF_6 [2,5]), however the magnitude of the hold up in this regions is difficult to estimate as it depends on such factors as plant layout, frequency of process upsets, maintenance and cleanout procedures, and throughput. Thus, it makes more sense to revisit sensitivity of detectors used by IAEA inspectors and responsible facility personnel in NDA applications for measuring special nuclear material hold up at uranium enrichment plants especially

The various distribution of hold nuclear material complicate not only static measurements performed primarily by the personnel of the facility analytical laboratory in hold up drums, etc., in pipeline at enrichment plants when the uranium hexafluoride is withdrawn from the enrichment cascade but also measurements in dynamic, when the UF_6 within the cascade. This verification technique is named online enrichment measurements (on-line enrichment monitoring) and it is aimed to presence of LEU in the cascade.

At the time being the IAEA has only two authorized online enrichment measurement techniques: CHEM (continuous enrichment monitoring) and CEMO (Cascade Header Enrichment Monitor). The devices uses a passive gamma measurement combined with X-ray fluorescence (the two-geometry method) [2, 3, 4, 18] to measure the enrichment of UF_6 gas in process piping outside the confines of the enrichment hall. Due to operator sensitivity to enrichment levels even in outlet piping, numerical enrichment values were not displayed quantitatively but were displayed only as HEU YES or NO, with a false alarm probability of 0.001 that the intrinsic UF_6 was high enriched ($\geq 20\%$). The advantage of the CEMO system is that it is a nonintrusive one, providing timely, continuous detection of HEU production and monitoring of enrichment in a manner that is acceptable to the

operator. Nevertheless it has a number of disadvantages: it is permanently installed; measurements are not applied at random points; dependent on pipe geometry and materials; uses a source that has to be replaced every 2 years; temperature sensitive and requires an optimal gas pressure and requires difficult calibration, and does not distinguish between uranium in the solid (plated on the pipework) and gas phases. From the Agency's standpoint, the greatest shortcoming of CHEM is that it is not a continuous, unattended system. The disadvantage of the continuous enrichment monitor (CEMO) is also that x-ray absorption varies with pipe diameter and wall material so it cannot be used at some plants or on certain headers. The Cd^{109} source used for normalization has a relatively short, 464 day half life. The system does not work at low, cascade level pressures. It is also expensive. CEMO provides the IAEA with the minimum information necessary to facilitate adequate safeguards while using software to shield sensitive information from inspectors, but a demarcated information barrier should not measure an operator's sensitive parameter at all. From an operator's perspective there should be no conceivable way for inspectors or Agency technicians to access sensitive information through a non-procedural backdoor. This may be why some facilities might deprecate its use, since it actually measures gas pressure and enrichment levels while only displaying an HEU vs. LEU reading. But undoubtedly is measurement results from the equipment should be independent of pressure and build-up of deposits in pipework. The strong necessity to revisit this safeguards issue was also emphasized at a technical meeting organized by the IAEA convened in Vienna, Austria in April 2005 in order to address future challenges for safeguarding GCEPs as well as improve current verification procedures and complement them with more reliable practices to enhance the current Hexapratite safeguards project for enrichment plants [15].

5. Conclusions

The current tendency in the world nuclear fuel cycle development shows that more developing states are trying to work out indigenous isotope-separation capability. However the recent initiatives such as those proposed by such highly-developed states with mature enrichment capability as Russia (Multinational Nuclear Fuel Cycle Center), US (Global Nuclear Energy Partnership), 6-Party proposal (USA, Germany, France, Russia, Great Britain, the Netherlands), the NTI offer for 50 mil.\$ for an IAEA controlled "real" fuel bank and some other initiatives

could curb to some extent the proliferation of enrichment technology. This arrangement seems to be beneficial for some states (Kazakhstan, etc.). It is therefore likely that a growing number of countries will have access to centrifuge technology in the near future. Nevertheless the experience of Iran and some other countries illustrates the opposite tendency. It is still open to question which tendency will dominate, but undoubtedly is uranium enrichment plants must be used only for peaceful purposes and that could only be performed by means of reliable verification system. In the light of the recent developments (the increase in facility's efficiency – facilities now exceed the 2,000t-SWU/yr size on which HSP assumptions were made, and developments in centrifuge cascade technology) have led to more flexible cascades and methods of operation. The measurement of the nuclear material hold up remains to be one of the principal safeguards challenges and so as to meet with it and therefore enhance the proposed Model Safeguards Approach for Enrichment Facilities subsequent safeguards R&D for GCEPs should also be aimed at developing new methods and equipment that will allow decreasing measurement errors.

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