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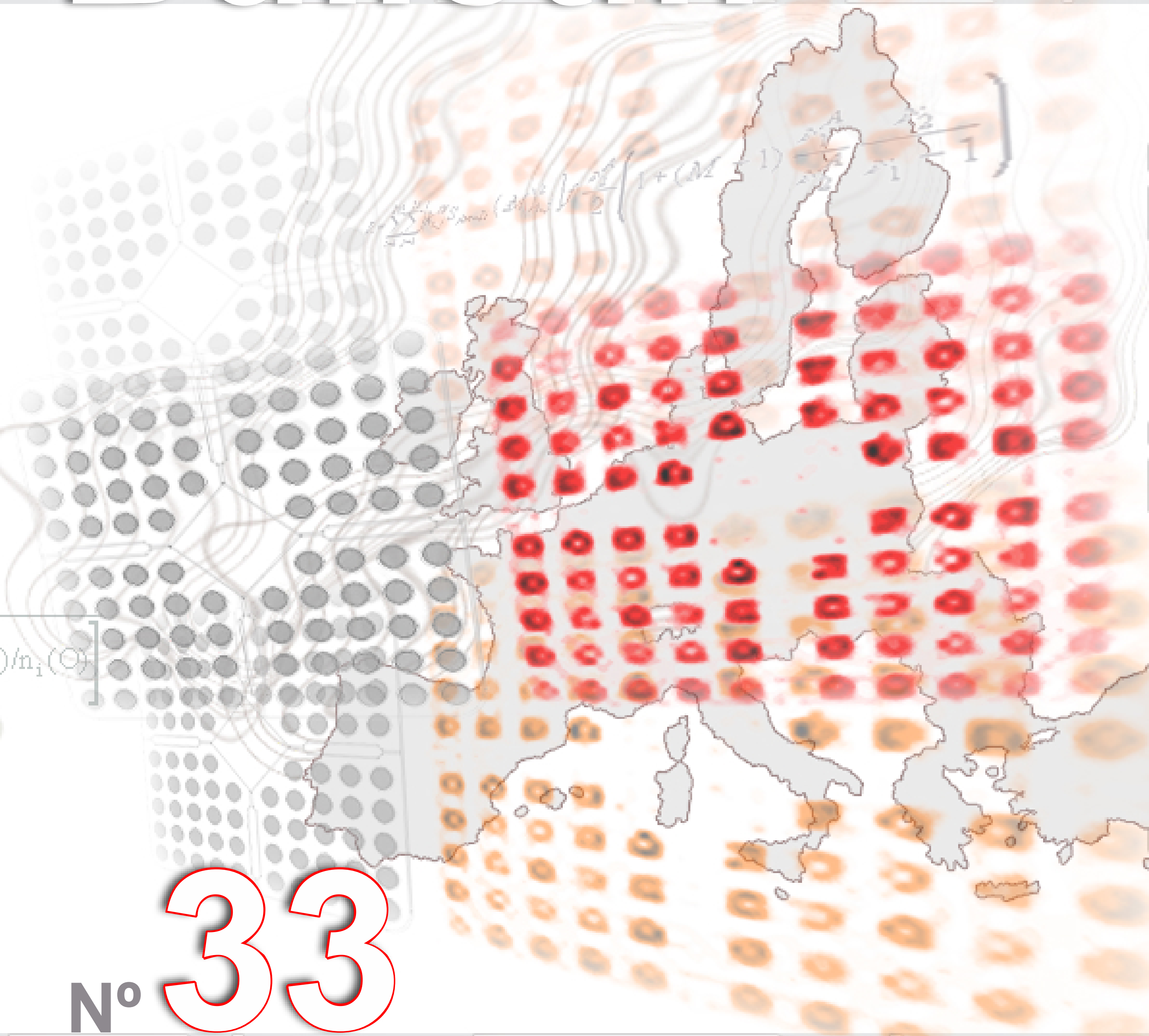
ESARDA

European Safeguards Research Development Association

Bulletin



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ESARDA Bulletin

European Safeguards Research and Development Association

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This section of the Bulletin has been created in order to encourage our readers to express their views on anything associated with the ESARDA activities. All suggestions and comments are very welcome.

Editorial

To Peer Review or Not To Peer Review, That is the Question

Presentation by scientists of the results of their research to others is an essential part of the scientific enterprise. The nature of scientific work is to reach the truth through a series of increasingly accurate approximations. The results of the research will never be definitive, but are transitional. The goal of scientists is to reach perfection, but they cannot achieve it. It follows that neither a paper presenting new results of observation or theory, nor a proposal for a new investigation, can be perfect. They can only be "good enough". Scientists understand, qualify and quantify precisely physical phenomena that are, for the majority of us, difficult to understand but they cannot define a precise measurement of "good enough". Scientific experts or specialists must assess what "enough" means objectively. Their aim is to ensure that non-specialists, who cannot reach an informed opinion about a theory or discovery, obtain sufficient faith in the benefits of scientific progress.

The assessment of research results and theories by individuals, however well informed in a particular field of their experience, introduces a factor of subjective opinion into seemingly objective science. The ancient Greeks, who originated science as a specific endeavour based on logical argument and empirical tests, realized its susceptibility to subjective opinions. The Greek way of dealing with possibly biased opinions was to conduct debates between scientists, to produce mathematically exact descriptions and to run empirical tests of statements. Broad discussions and empirical testing were the foundations of the "peer review".

Peer review is a staff development process that is widely used in training and other professional contexts. The basic idea is that the person who is concerned about some aspect of their own work invites a colleague to review the quality of what he or she is doing. In practice we are doing this all the time. It is very common for someone to say - 'Do you have a little time to tell me what you think of this?'; or to ask - 'Has anyone thought of a better way?'

It is not possible for an individual author or research team to spot every mistake or flaw in a complicated paper. This is not because deficiencies are like needles in a haystack, but because, in new and specialised topics, an opportunity for improvement may stand out only to someone with special expertise or experience. Therefore, showing work to others increases the probability that weaknesses will be identified and advice and encouragement will be given.

Even after peer review had become a common practice, some famous papers were published without review, perhaps due to the complexity of the subjects. Examples where the editors showed the wisdom to publish papers without review include:

- Albert Einstein's paper on the special theory of relativity, issued by Annalen der Physik in 1905 ; the journal's editor in chief, Max Planck, recognized the strong interest of publishing such ideas.
- Watson and Crick's paper on the structure of DNA published in Nature in 1951.
- Abdus Salam's paper on the weak and electromagnetic interactions which elucidated the interaction of the weak nuclear force with the electromagnetic force, published in the proceedings of the Nobel symposium held in 1968.

The history books are full of stories of geniuses condemned to obscurity, poverty and ostracization by their peers: Socrates, who committed suicide in 399 BC; Galileo, placed under house arrest in 1632; and Tesla, deprived of research funding in 1932, are just a few. Only they know the pain and suffering experienced as a result of arrogant, narrow minded and unjust condemnations.

On the other hand, Peer Review has saved us (although not in all cases) from countless frauds and other wastes of time, effort and money. No example will be given, to keep it away from the lights of history. Suffice to say, some well known scientists have avoided giving references in their papers whilst others have taken the road of pseudo science.

The peer review is not the panacea, but it is important; it is the process by which scientists seek to guarantee that good quality research is published. Peer review also has a role in maintaining public confidence in scientific research.

The peer review process provides an opportunity to demonstrate, and a tool to improve, the quality of Safeguards work through the ESARDA Bulletin. By choosing the peer review process for the bulletin, ESARDA will become a touchstone of the exchanges on that topic.

The Editorial Committee will have to be “the guardian of the temple” of the peer review process, in regard to respecting the opinion of the authors and referees whilst actively promoting debate.

The process of the peer review is defined and approved by the editorial committee (including the role of referees, process and a toolkit). Peer review subjects an author’s work or ideas to the scrutiny of one or more others who are experts in the field. These referees each return an evaluation of the work, including suggestions for improvement, to an editor or other intermediary (as ESARDA Editorial Committee). Evaluations usually include an explicit recommendation of what to do with the manuscript or proposal, often chosen from a menu provided by the journal. Most of the recommendations could be along the lines of the following:

- To unconditionally accept the manuscript or proposal,
- To accept it in the event that its authors improve it in certain ways,
- To reject it, but encourage revision and invite resubmission
- To reject it outright

It is the intention that understanding and encouragement, rather than strict criticism, will ensure that the bulletin promotes the progress of science and scientists.
As chairman of the ESARDA Editorial Committee, I have the honour to introduce the first issue of the Bulletin that includes a section devoted to peer reviewed papers. Readers of the ESARDA Bulletin in particular, but also specialists from safeguards community are encouraged to submit scientific original contributions for the peer reviewed section of the Bulletin.

Bruno Autrusson,
ESARDA Editorial Committee Chairman

Article drawn by the following references

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On peer review Dale Pond, Summer 1992

Scientific Papers (peer reviewed)

Spectral Tagging

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Abstract:

This research examines the feasibility of spectral tagging, which involves modifying the spectral signature of a target, e.g. by mixing an additive with the target's paint. The target is unchanged to the human eye, but the tag is revealed when viewed with a spectrometer. This project investigates a layer of security that is not obvious, and therefore easy to conceal. The result is a tagging mechanism that is difficult to counterfeit. Uniquely tagging an item is an area of need in safeguards and security and non-proliferation.

The powdered forms of the minerals lapis lazuli and olivine were selected as the initial test tags due to their availability and uniqueness in the visible to near-infrared spectral region. They were mixed with paints and applied to steel. In order to verify the presence of the tags quantitatively, the data from the spectrometer was input into unmixing models and signal detection algorithms. The mixture with the best results was blue paint mixed with lapis lazuli and olivine. The tag had a 0% probability of false alarm and a 100% probability of detection. The research proved that spectral tagging is feasible, although certain tag/paint mixtures are more detectable than others.

Keywords: spectral tagging; hyperspectral tags

1. Background

1.1. Introduction

This study investigates the feasibility of spectral tagging. Spectral tagging involves modifying the spectral signature of an item such that the item is unchanged to the human eye, but is unique when viewed with a sensor with good spectral resolution. Spectral tagging capitalizes on the emerging field of spectroscopic remote sensing (where neither the signature nor location are necessarily known), but has the distinct advantage of locating a signature known only to the investigators. Often times, it's at a specific location, but not necessarily.

The goal of this study is to assess the feasibility of spectral tags. Spectral tags could be applied to a variety of items. A spectrometer could query the items, obtain a signature, and through signal processing and detection algorithms, determine if the spectral tag is present.

Section 1 reviews background information on tagging. Section 2 presents the methodology of the study and equipment used, Section 3 contains the more significant results, and Section 4 covers signal processing. The summary, conclusions, and recommendations are included in Section 5.

1.2. Tagging

Identification tags can be divided into two categories: active and passive. Active tags (ones which transmit) include RF tags that provide one or two-way communication. An example is a tag that sends a unique signal to a receiver to identify itself. Active tags require power, can be expensive, can break, and are not necessarily covert.

Passive tags include visual items such as barcodes, serial numbers, and hidden tags, such as spectral tags, that must be read with an instrument. The disadvantage of visual tags is that an adversary could potentially remove the tag, or counterfeit it. However, they are typically easy to produce and inexpensive. Hidden tags are difficult to counterfeit since only few people know their location; however, they require special instrumentation to detect.

2. Methodology

The experiment objective was to accurately detect additives, or "tags", in paint samples and minimize the probability of detecting the tags when they were not present. The paint samples were supposed to visibly appear identical so that the presence of a tag was unknown until signal processing and detection algorithms were applied.

A simulation system was developed which consisted of paint and a steel saw blade. The spectroscopy equipment had to be relatively inexpensive and thus the region of the spectrum was limited to the visible and a portion of the near-infrared. Additives could be anything that didn't significantly change the appearance of the paint to the human eye and had unique signatures in the spectral range of the spectrometer.

2.1. Spectroscopy Equipment

The spectrometer used for this project was the Ocean Optics, Inc., HR2000 High-Resolution Fiber Optic Spectrometer. This spectrometer was chosen because of its high spectral resolution (maximum of 0.065 nm), its small size (hand-held), and low cost. High spectral resolution was needed because the range of wavelengths was relatively small and subtle differences needed to be resolved. Also, high resolution now would help predict the resolution required in a future system, especially if coarser-resolution imaging spectroscopy was considered. The HR2000 can be responsive from 200 – 1100 nm. Selection of gratings and entrance slits affect the specific range and resolution. The spectrometer used for this project is responsive from 481 – 918 nm and has a spectral resolution of 0.43 nm. Spectrometers with broader and/or higher wavelength ranges (i.e. up to 2500 nm, or 2.5 microns) can cost an order of magnitude more since the detector changes from silicon to something such as indium-antimonite. The smaller range of wavelengths is acceptable for this project since minerals can be found with distinct signatures that fit within the range. However, a broader range would provide a more distinct signature and perhaps be more covert (since our spectrometer overlaps with the visible) at the expense of greater cost.

The overall system comprised the spectrometer, OOIBase32 operating software, a light source, and sampling optics. The light source sends light through a fiber optic cable to the sample holder where it interacts with the sample. The light is then collected and transmitted through another fiber optic cable to the spectrometer, which performs measurements and converts the data into digital information. That information is transferred to the operating software through a USB port on the computer. Figure 2.1 shows how the optics of the spectrometer operate and Figure 2.2 shows the HR2000 with the USB connection to the computer, the fiber optic cable, reflection probe, diffuse reflectance standard, and light source.

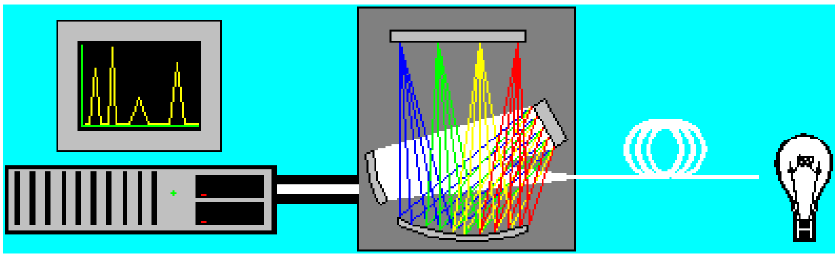

Figure 2.1: Light enters the spectrometer (middle gray object) through a slit and filter, reflects off of the collimating mirror, is diffracted by the grating, and reflects off the focusing mirror to the Silicon CCD detector array (taken from Ocean Optics). The object of interest would be illuminated by the light source using a split fiber cable (see reflection probe in Figure 2.2).

Figure 2.2: Ocean Optics HR2000 spectrometer with USB cable (square) and fiber optic cable (left); reflection probe and diffuse reflectance standard (center); tungsten halogen light source (right) (taken from Ocean Optics). The long metallic end of the reflection probe is used for sampling of the object, while the two red ends are connected to the light source and the spectrometer.

The OOIBase32 Spectrometer Operating Software is an acquisition and display program. The software receives the data through the USB port and displays real-time spectral information. The Reflection Probe (R200) is a fibre optic cable that connects to the light source and the spectrometer, and has an open end for probing a sample. It is shown in Figure 2.2 (center), along with the Diffuse Reflectance Standard, which is used for a reference spectrum and reflects greater than 95% across the spectrum of the spectrometer. The LS-1 Tungsten Halogen Light Source (Figure 2.2 right) provides the illumination of the sample.

2.2. Surface to be Painted

The items of interest in these applications are made primary of steel, and thus steel was used for the painted surface. A steel saw blade (Figure 2.3) was used as a simulation surface. It was cleaned with Lacquer Thinner before paint was applied to remove any dust particles and films that might affect the spectral signature.

Figure 2.3: Steel saw blade used for painted surface and a coin for size reference.

2.3. Selected Additives

The objective was to identify additives that had distinguishable spectral shapes in the 500 to 1000 nm region and did not visually affect the paints. The U.S. Geological Survey (USGS) has a spectral database for minerals and thus it was examined for candidates. Lapis lazuli and olivine were common minerals and had unique features and thus selected. Figure 2.4 shows the USGS spectral signature of olivine.

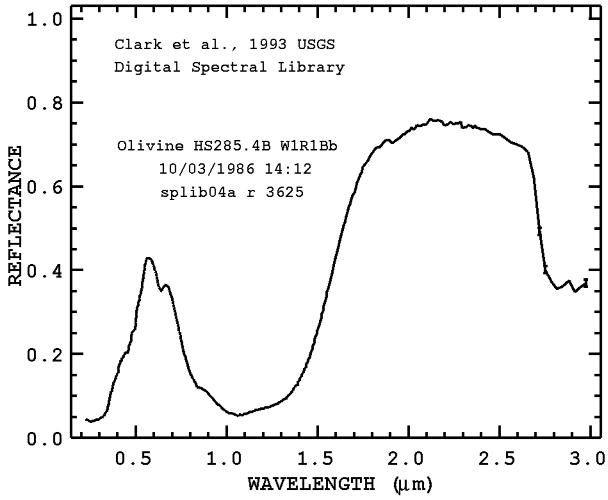

Figure 2.4: Olivine spectrum (taken from the USGS Spectral Library).

2.4. Mixtures

The lapis lazuli and olivine were each mixed separately with blue, orange, and brown paints (however, only blue paint will be discussed in this paper), and also one sample was created with the minerals combined. A total of four samples were applied to the saw blade (one was simply the blue paint). The reflection probe holder was moved over each sample in twenty different places and spectral signatures were captured.

Figure 2.5: Blue paint samples on saw blade. Starting at bar code going clockwise: blue paint/olivine, blue paint/lapis, blue paint alone, and blue paint/lapis/olivine.

All of the blue paint samples were slightly different in color. The samples with olivine appeared to brighten the paint slightly, while the lapis lazuli darkened them. The goal was to *not* be able to distinguish same color-based samples from one another. Clearly, the minerals did have some affect on the color. This would not be a problem if the target was completely painted with the tag/paint mix, or the tag was segregated from the paint alone (i.e. one side of the target) and thus visual comparison was more difficult. In future studies, minerals that do not affect the color of the paint should be found. The minerals should only affect the signature beyond the visible region.

3. Results

3.1. Spectral Properties of Paint on Steel Saw Blade

This section shows the spectra of the blue paint (Figure 3.1) on the steel saw blade. Eight of the samples are shown due to limitations on the number of overlays in the software.

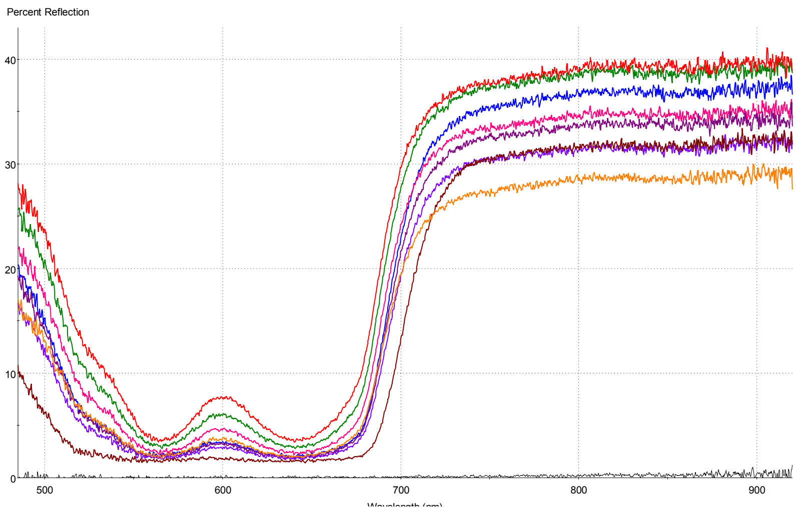

Figure 3.1: Blue paint spectrum (Percent reflection on y-axis vs. wavelength in nanometers on x-axis). The y-axis starts at 0% and ends at 40% (incrementing 10%), while the x-axis goes from just below 500 nm to just above 900 nm (incrementing 100 nm).

3.2. Spectral Properties of Powdered Minerals

The spectra of the lapis lazuli and olivine are shown in Figures 3.2 and 3.3. The high reflection below approximately 550 nm is in the visible and is probably due to the bluish color of the lapis lazuli. Olivine has a slightly greenish color and thus the reflectivity in the visible is probably due to the green. Reflectivity of the minerals in the visible should ideally match that of the paint, and differ from the paint in the near infrared. Notice that the reflection scales are different so that the characteristics of each mineral are more visible.

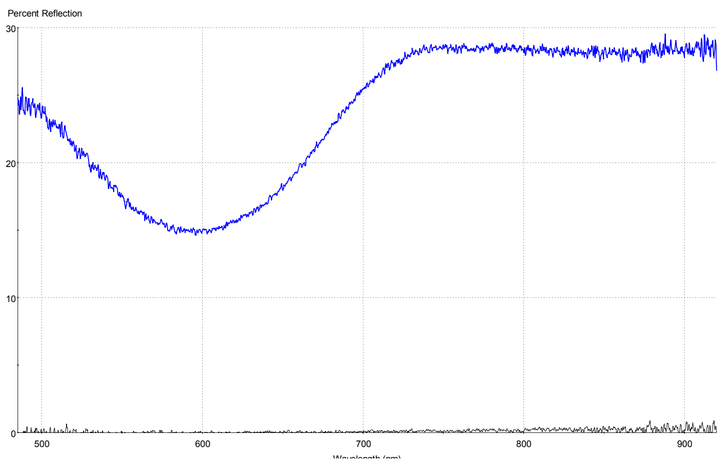

Figure 3.2: Lapis lazuli spectrum. The y-axis goes from 0% to 30% in 10% increments, and the x-axis goes from just below 500 nm to just above 900 nm in 100 nm increments.

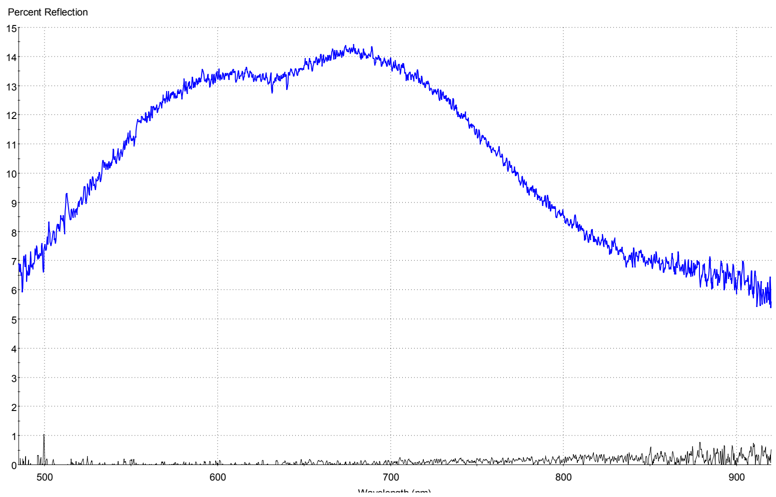

Figure 3.3: Olivine spectrum. The y-axis goes from 0% to 15% in 1% increments, and the x-axis goes from just below 500 nm and just above 900 nm in 100 nm increments.

3.3. Spectral Properties of Paint / Mineral Mixtures

Spectra at twenty different locations of each sample were collected; however, the following graphs show one spectrum for the mixture and one for each component (paint and mineral/s). The shown component spectra are the averages of the twenty samples taken. All twenty mixture samples are used in the unmixing models. The scales are adjusted to reveal characteristics about the mixtures. The colors are defined in the captions.

In Figure 3.4, visually it appears as if in the region from 525 – 675 nm, the spectral shape of the blue paint/lapis mixture (shown in blue) follows that of the blue paint (shown in green). We would expect this since the blue paint reflects less than the lapis (shown in red) and thus absorbs photons before they are able to interact with the mineral. The small difference in percent reflection in this area of the spectrum (part of the visible) between the blue paint and the mixture probably accounts for the slight visual difference. (The same assumption concerning differences in reflectivity in the visible region is made throughout this section.) We assume that the lapis is pulling the reflectivity slightly higher. As the wavelength increases beyond 700 nm, the spectral shape of the mixture follows the lapis, which has lower reflectivity here than the blue paint alone. Ideally, the spectrum of the mixture in the visible should match that of the paint both in shape and percent reflection (so that to the human eye, the paint and tag/paint appear identical), and beyond the visible, the spectrum of the mixture should differ from that of the paint (so that the signal processing models can distinguish between components).

In Figure 3.5, the reflectivity of the blue paint/olivine mixture (shown in blue) again follows the spectral shape of the paint (shown in green) in the region below 700 nm. However, it is slightly more reflective (and thus brighter visually) than the paint alone due to the olivine (shown in red). Between 700 and 800 nm, the reflectivity of the mixture spectrum sharply increases, perhaps due to the small reflective peak in the olivine, but is closer to the paint spectrum and even further from the olivine spectrum. The reflectivity decreases past 800 nm with the decrease in reflectivity of the olivine.

In the region below 500 nm in Figure 3.6, we assume that the olivine (shown in purple) acts to pull the signature of the blue paint/lapis/olivine mixture (shown in blue) down. Next, the mixture follows the spectral shape of the paint (shown in green). After about 725 nm, one or both of the minerals pull the reflectivity of the mixture lower than that of the paint alone, but it is not obvious which one. It appears that around 900 nm, the olivine acts to again decrease the reflectivity.

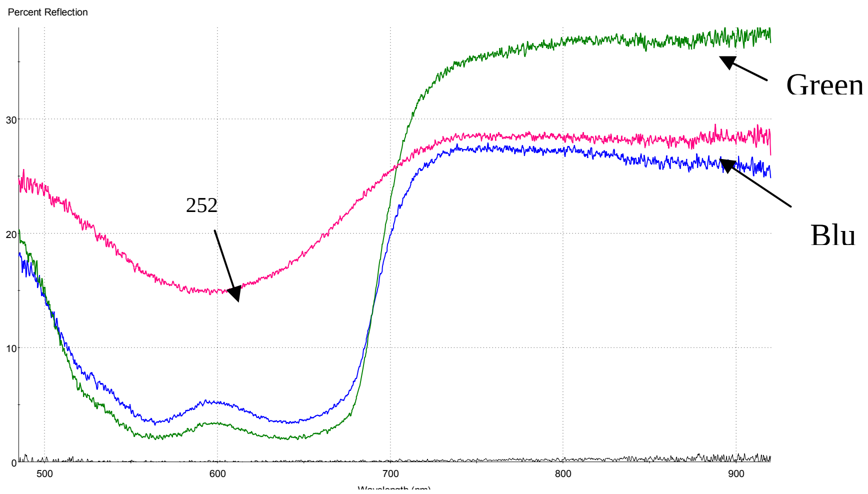

Figure 3.4: Spectrum of blue paint and lapis mixture (blue), blue paint (green), lapis (red). The y-axis goes up to 40%.

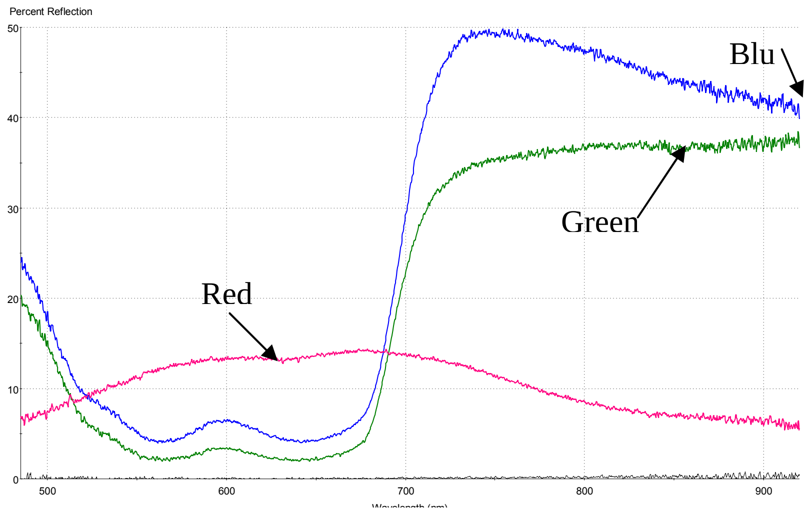

Figure 3.5: Spectrum of blue paint and olivine mixture (blue), blue paint (green), and olivine (red). The y-axis goes up to 50%.

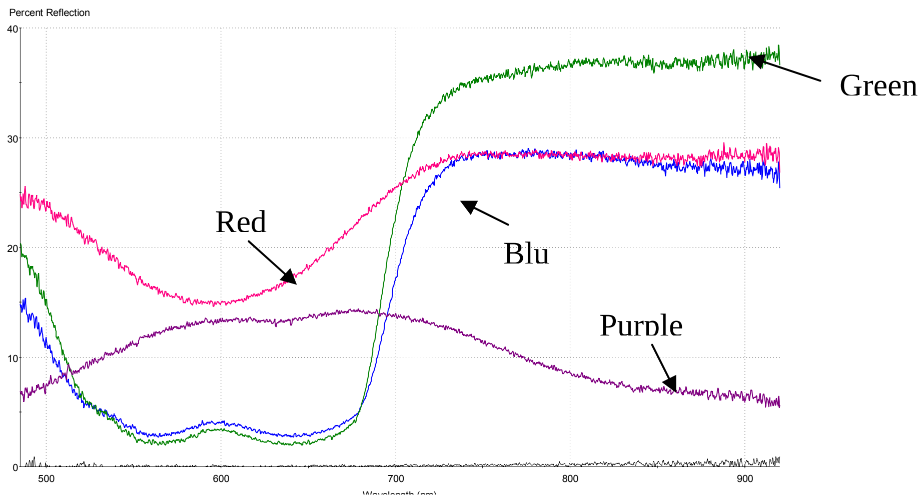

Figure 3.6: Spectrum of blue paint, lapis, and olivine mixture (blue), blue paint (green), lapis (red), and olivine (purple). The y-axis goes up to 40%.

4.0. Signal Processing

The spectra of the mixtures must be mathematically decomposed into *endmembers*, or constituents, and *abundances,* which indicate the proportion of each endmember in the mixture. This process is known as "spectral unmixing". Unmixing can be either linear or nonlinear. Both of these models were applied to the collected spectra and the results of the analysis begin in Section 4.4. The next three sections explain the linear unmixing model, nonlinear unmixing model, and signal detection theory.

4.1. Linear Unmixing

The linear unmixing model assumes that the reflectance spectrum of a mixture is a linear combination of the reflectance spectra of the endmembers. It is typically used when the endmembers are spatially segregated from one another. For M endmembers, each being sampled at L spectral bands, where **m** is an Lx1 vector that represents the mixed sample, $\mathbf{b}_i$ are the Lx1 endmember spectra (averaged from twenty samples) that make up the columns of a LxM matrix **B**, a_i are the fractional abundances of the endmembers, and **w** is a noise vector.

$$\vec{m} = \sum_{1}^{M} a_i \vec{b}_i + \vec{w}$$

4.2. Nonlinear Unmixing

If the mixture is "intimate" (not spatially separated on the photon scale), then light is multiply scattered amongst the endmembers and the process becomes nonlinear. We used a nonlinear unmixing model represented by, where i is the number of endmembers, **m** is the spectrum of the mixture and is Lx1, and $\mathbf{b}_i$ is Lx1.

$$\vec{m} = \vec{b}_1^{\,a_1} \vec{b}_2^{\,a_2} \ldots \vec{b}_i^{\,a_i}$$

4.3. Signal Detection Theory

Once the fractional abundances of each endmember have been calculated, a decision is required as to whether the tag is present. If the fractional abundance of an endmember is greater than some threshold *t*, then a "yes" decision is made. A "yes" decision when the tag is actually present is known as a hit. P_d represents the probability of a hit, or detection. A certain number of decisions will incorrectly be "yes" when the tag is not present due to the fractional abundance returned from the unmixing model. This is known as a false alarm and is represented as a probability, P_{Fa}. Each time the threshold *t* is changed, P_d and P_{Fa} are updated. These probabilities are plotted on an ROC curve (receiver operating characteristics) for each new value of *t*. The y-axis is the probability of correctly detecting the tag, P_d, while the x-axis represents the probability of a false alarm, P_{Fa}. The objective is to set a threshold to maximize P_d (ideally 100%) and minimize P_{Fa} (ideally 0%).

4.4. Results

This section presents the ROC curves for the various mixtures and unmixing models. Triangles represent the ROC for the linear unmixing model and circles represents the ROC for the nonlinear unmixing model. The data points are each of the twenty measurements taken on a particular sample.

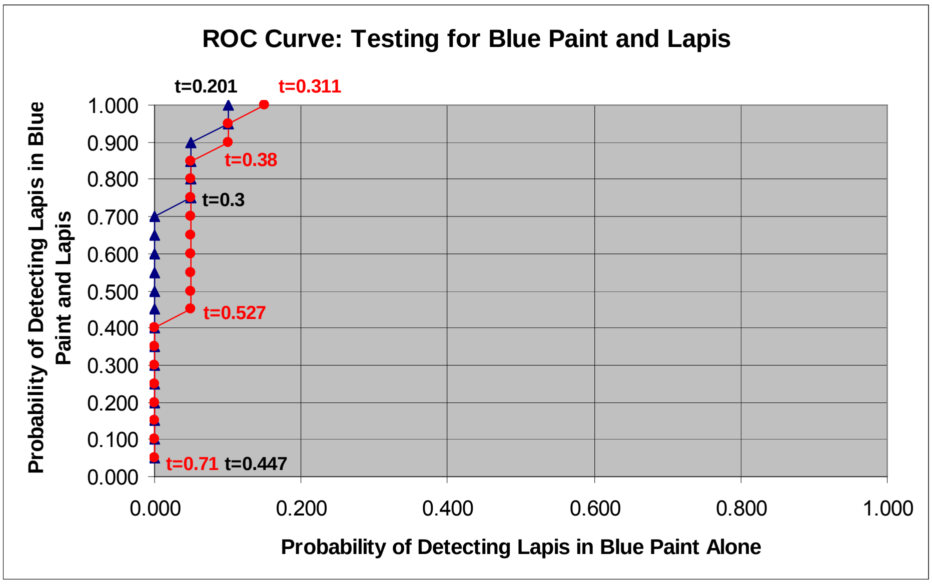

Figure 4.1: ROC curve for blue paint and lapis endmembers. Triangles = linear, circles = nonlinear.

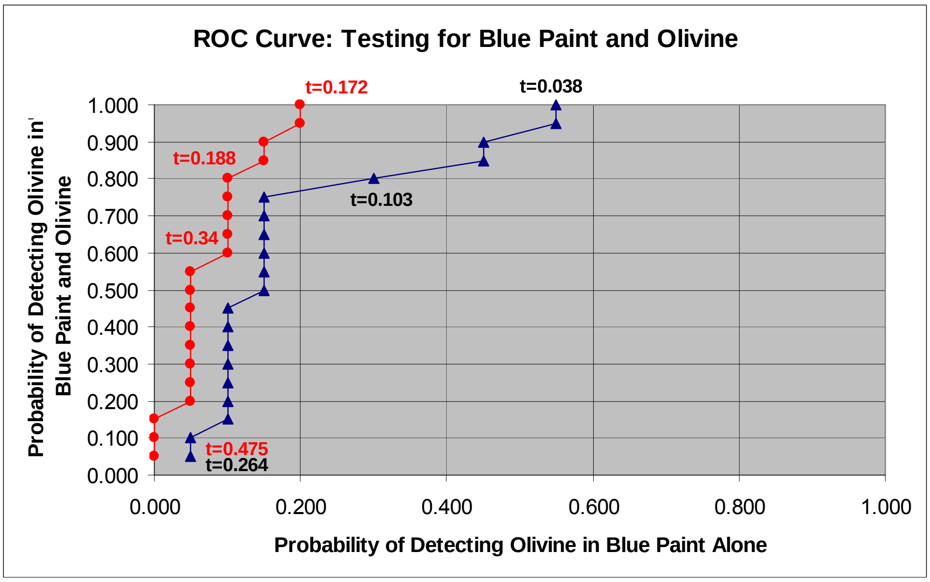

Figure 4.2: ROC curve for blue paint and olivine endmembers. Triangles = linear, circles = nonlinear.

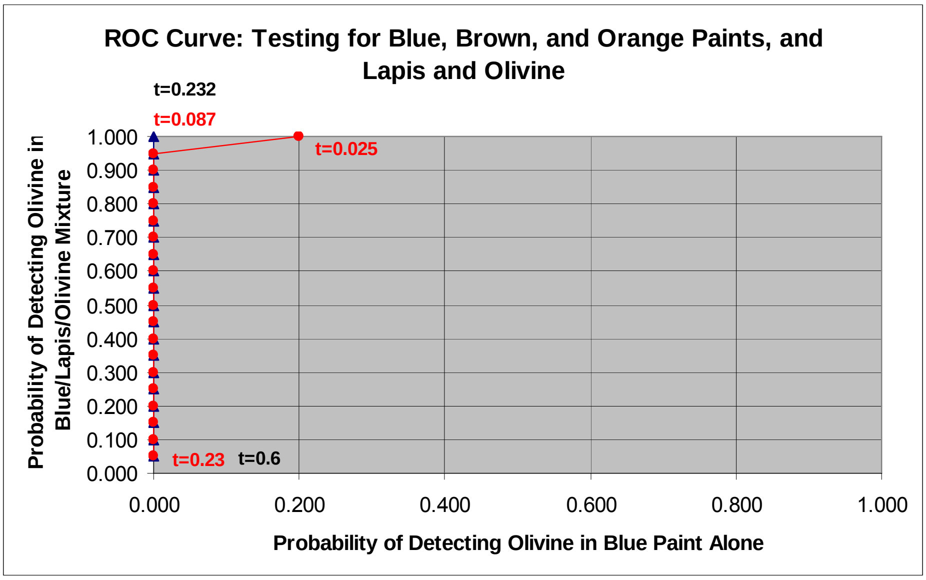

Figure 4.3: ROC curve for three paints, lapis, and olivine endmembers (seeking olivine). Triangles = linear, circles = nonlinear.

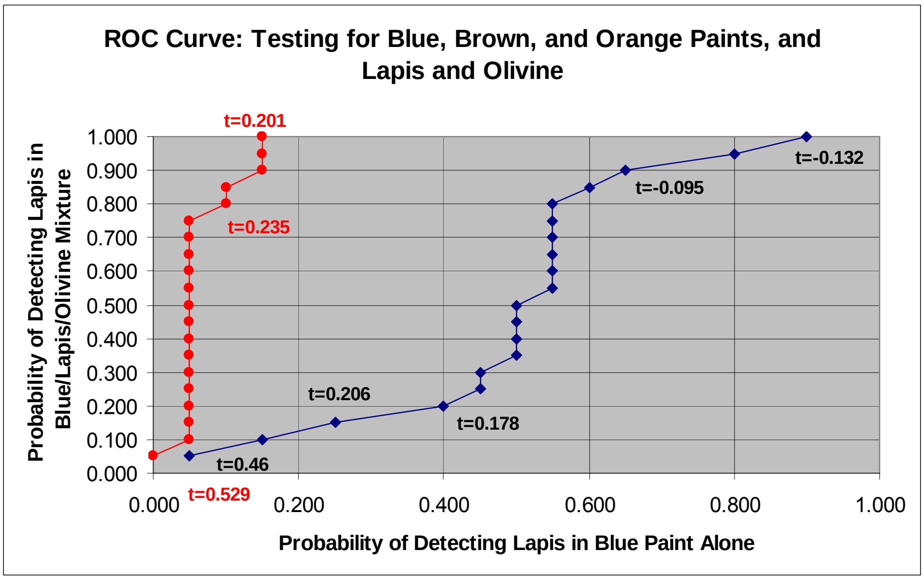

Figure 4.4: ROC curve for three paints, lapis, and olivine endmembers (seeking lapis). Triangles = linear, circles = nonlinear.

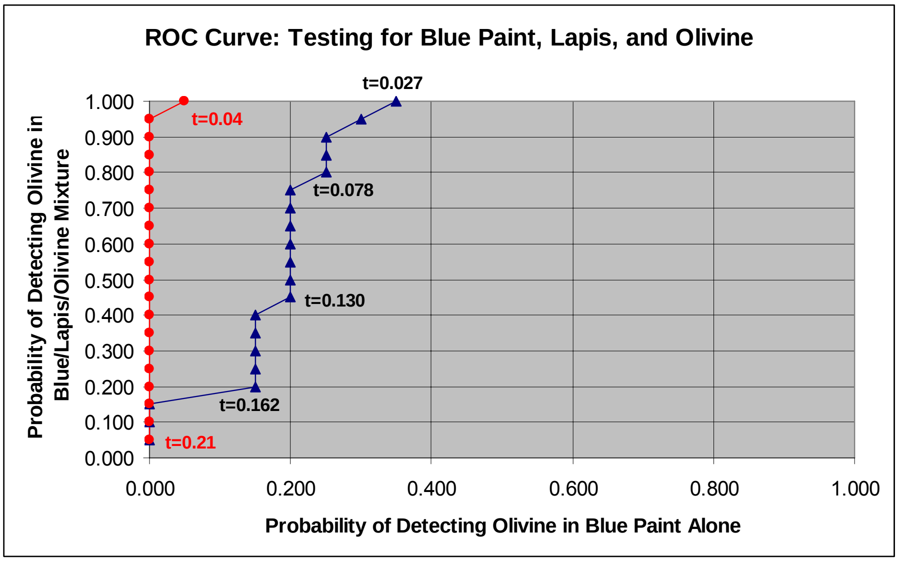

Figure 4.5: ROC curve for blue paint, lapis, and olivine endmembers (seeking olivine). Triangles = linear, circles = nonlinear.

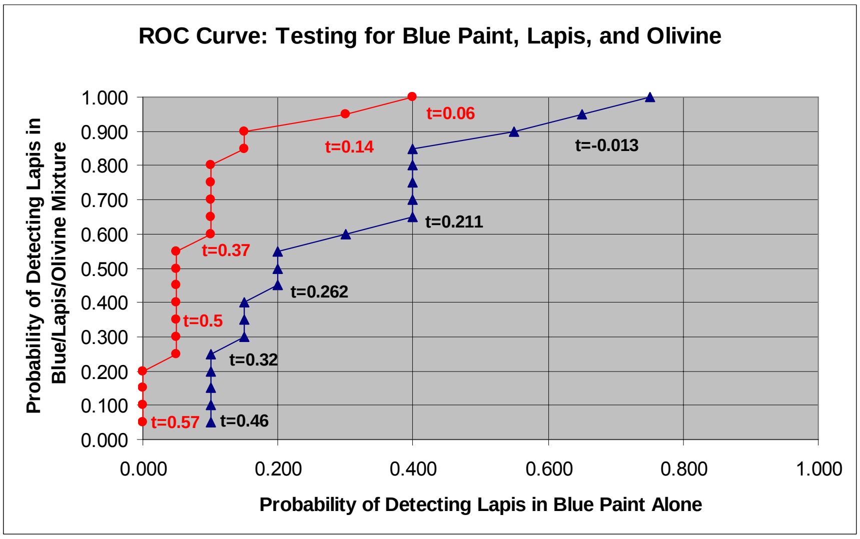

Figure 4.6: ROC curve for blue paint, lapis, and olivine endmembers (seeking lapis). Triangles = linear, circles = nonlinear.

Overall, for the blue paint samples, the best results (100% P_d and 0% P_{Fa}) came from the blue/lapis/olivine mixture, tested linearly for blue, brown, orange, lapis, and olivine, seeking olivine (Figure 4.3). (The brown and orange paint were false endmembers, and provide the model with more information about what the mixture is NOT. For example, with two endmembers, the model tries to map the fractional abundance coefficients onto a 2-dimensional plane when really 2048 dimensions are possible. The false endmembers give the model more dimensions to map the abundances to.) The thresholds were all positive, and the spectral shape of the mixture deviated towards the shape of the minerals beyond 725 nm. The worst results (100% P_d and 90% P_{Fa}) came from the same mixture, tested for the same endmembers in the linear model, but seeking lapis (Figure 4.4). In this case, negative thresholds were needed to achieve 100% P_d. Because of the poor results for seeking lapis, we assume that the olivine (which produced good results as seen in Figure 4.3) was the mineral most affecting the spectrum of the mixture.

5.0. Summary, Conclusions, and Recommendations

The objective was to determine the feasibility of spectral tagging, which in this project involved adding a tag to a target's paint such that the target is unchanged to the human eye, but the tag is revealed when viewed with a spectrometer.

The powdered forms of the minerals lapis lazuli and olivine were selected as the initial test tags due to their availability and uniqueness in the visible to near-infrared region of the spectrum. They were mixed with blue paint and applied to a steel surface. Unfortunately, the minerals slightly altered the coloring of the paint, which means that if these tags were placed on only a part of a painted surface, they may be visually noticeable. In order to verify the absence or presence of the tags quantitatively, the data from the spectrometer was input into unmixing models and signal detection algorithms.

> Overall, the blue paint/lapis/olivine mixture processed with the linear unmixing model had the ideal ROC curve: 100% detection and 0% false alarm. We were trying to detect olivine in the mixture and tested the mixture against blue paint, brown paint, orange paint, lapis, and olivine. The lowest threshold (fractional abundance in this case) was 0.232, and the spectral shape of the mixture followed that of the minerals in some region of the spectrum.

Some observations on parameters affecting the probability of false alarm were: **(1)** anytime the fractional abundances were negative, the probability of false alarm was greater than 75%, **(2)** positive fractional abundances from the linear unmixing model AND a mixture spectrum that deviated towards the shape of the tags resulted in P_{Fa}'s lower than 35%, **(3)** positive fractional abundances from the nonlinear unmixing model and a mixture spectrum that mostly followed the spectral shape of the paint resulted in P_{Fa}'s lower than 45%, and **(4)** for positive fractional abundances in the same tag/paint sample and tested endmembers, the higher the fractional abundance (threshold), the lower the P_{Fa}. For instance, the blue, lapis, and olivine mixture that was tested for blue, lapis, and olivine with the goal of detecting olivine had the following results: linear unmixing model P_{Fa} = 35% with fractional abundance of 0.027 and for nonlinear unmixing model P_{Fa} = 10% with fractional abundance of 0.04. All four general observations lead to the conclusion that the fractional abundances of the tags influence the detection. The amounts of each mineral added to the paint were not consistent or measured. If the concentrations were accurately measured and varied, more conclusions might be available as to the quantitative effect of the fractional abundances of the tags.

The linear unmixing model had the lowest overall P_{Fa} of 53% compared to 60% P_{Fa} for the nonlinear unmixing model. For samples based on blue paint, the nonlinear model had an overall P_{Fa} of 20% versus 44% for linear. When the thresholds were positive, both models had P_{Fa} of 23%. For negative thresholds, the linear and nonlinear models were similar, with P_{Fa} of 90% and 95%, respectively.

Other unmixing algorithms exist but were not examined in this study. For instance, here each endmember was modelled with a deterministic spectral signature; however, stochastic models are possible which allow the spectral signature to vary.

There are many different regions of the spectrum in which the signature of a tag might appear unique. This study only involved the visible to near-infrared region due to the high costs of spectrometers in other regions. Increasing the spectral range could provide more opportunities to exploit unique spectral features of minerals.

Other tags are possible using chemicals, metals, pigments, etc.; however, spectral libraries for minerals are being developed for remote sensing applications and are readily available. In this study, only two minerals, lapis lazuli and olivine were used, and thus 3 2-bit tags were possible (lapis, olivine, and lapis plus olivine). Future research could include additional minerals so that the tags could increase to higher bit – for example, if 4 minerals were used, then 15 4-bit tags would be available (2^4 – 1).

Tomography for partial-defect verification – experiences from measurements using different devices

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Abstract

Three devices of different types have been used in tomographic measurements for the purpose of partial-defect verification on the single-rod level. The devices range from a laboratory device used in measurements on a fuel model to an in-pool device used in measurements on irradiated fuel in a fuel-handling pool.

The tomographic technique accounted for in this paper involves measurements of the gamma-ray flux distribution around a fuel assembly followed by computer-aided reconstruction of the internal source distribution. The results are rod-by-rod values of the relative concentrations of selected gamma-emitting isotopes. Also cross-sectional images are obtained.

The tomographic technique presented here has proven to be robust and reliable. In laboratory experiments on a fuel model, reconstructions of relative rod-by-rod activities have been obtained with 1.5 % accuracy (1 σ). Using an in-pool device in measurements on fuel with a cooling time of about 4 weeks, data on fuel rods have been obtained in agreement with production-code calculations. Furthermore, tomographic images of good quality have been acquired.

The applicability of the tomographic technique for partial-defect verification on the single-rod level has been investigated and demonstrated. The gamma-ray source concentration reconstructed in a position corresponding to a removed or replaced rod has been significantly lower than that of normal rods.

Finally, requirements and properties of a device for tomographic measurements on nuclear fuel are discussed. It is argued that the use of a detector system with high energy resolution and high peak efficiency in connection to spectroscopic peak analysis is beneficial.

Keywords: safeguards, partial-defect verification; tomography; nuclear fuel; NDA

1. Introduction

International safeguards have addressed the need for verifying the integrity of nuclear fuel assemblies. A possible approach for such verification is the use of tomographic methods. In this paper, the technique called "Single Photon Emission Computed Tomography" (SPECT) is utilised to experimentally determine the internal distribution of radioactive nuclides in nuclear fuel assemblies.

The utilisation of the SPECT technique for safeguards purposes has been reported earlier (refs [1]-[5]). Removal of individual rods or groups of rods has been investigated, as well as replacement of rods with fresh fuel or fuel-like material. The investigations have indicated that the technique is applicable for partial-defect verification down to the single-rod level in both BWR and PWR fuel.

In Sweden, the use of a stationary tomographic device for safeguards measurements of nuclear fuel assemblies prior to difficult-to-access storage is discussed, ref. [6]. The discussion relates to a final-repository facility, where cooling times of several decades can be expected. At such a site, continuous measurements can be expected, implying the feasibility of stationary equipment offering high reliability and availability.

This paper accounts for three different experiments using various types of tomographic equipment. The experiments were performed in order to investigate the feasibility of the tomographic method for partial-defect verification. Although the main Swedish safeguards interest relates to fuel with long cooling time, the presented experiments also involve measurements in connection to revision shutdown, showing the applicability on fuel with a cooling time of a few weeks.

2. Tomography for partial-defect verification of nuclear fuel assemblies

Safeguards measurements on nuclear fuel may be desired after a cooling time (CT) ranging from a few days to several decades. Depending on the cooling time of the fuel, different isotopes may be relevant for tomographic measurements, depending on their concentration, half-life and decay modes. To be suitable, the isotopes should emit radiation of sufficient energy to allow the gamma quanta to escape from the assemblies. Some isotopes of interest are listed in Table 1.

Isotope	Gamma-ray energies [keV]	Half-life	Relevant CT
Ba-140[a)]	1596	12.8 d	<50 d
Zr-95	724, 757	64 d	30 d – 0.5 y
Ce-144[b)]	696, 2186	284 d	0.3 – 2 y
Cs-134	605, 796	2.1 y	1 – 10 y
Eu-154	1274	8.5 y	2 – 30 y
Cs-137	662	30 y	2 – 100 y

[a)] Ba-140 → La-140 that decays with a half-life of 40.3 h.
[b)] Ce-144 → Pr-144 that decays with a half-life of 17.3 m.

Table 1: Feasible isotopes for tomographic measurements.

Furthermore, different cooling times of the fuel imply different properties of the measured gamma-ray spectrum and overall intensity. This, in turn, sets different demands on the equipment e.g. with respect to energy resolution of the detector system and shielding of sensitive components.

2.1. Basic requirements of the equipment

A basic property that is required of a tomographic measurement device is the ability to record the gamma radiation in a large number of positions (typically 1 000-10 000) relative to the measured object. The position of the device relative to the object must be well known, as well as the geometry of the device. Inaccurate positioning information will harm the quality of the tomographic reconstructions.

The gamma-ray detectors must be fitted with a collimator system in order to define which sections of the object that will contribute to the measured intensity in a certain position and to obtain good spatial resolution of the source distribution. Furthermore, the detectors must be able to distinguish between the radiation of interest and other radiation.

The three devices used in this work are described in sections 3-5.

2.2. Tomographic reconstruction techniques used in this work

In the reconstruction procedure some assumptions have to be made, e.g. with respect to gamma-ray attenuation within the fuel. In this work, two different reconstruction techniques have been applied:

(1) Image reconstruction. Homogeneous gamma-ray attenuation is assumed within the cross-sectional area of the measured assembly. A pixel-based image of the source distribution of the selected gamma radiation is obtained in the reconstruction procedure.

(2) Rod-activity reconstruction. The nominal geometry of the measured fuel assembly is explicitly taken into account in the reconstruction procedure. The gamma-ray interaction in the assembly is modelled in detail. (See e.g. ref. [4].) The source concentration in the position of each individual fuel rod is obtained.

Method (1) is useful for getting an overall view of the measured cross section by inspecting the image obtained. The detailed modelling applied in method (2) gives the opportunity of determining highly accurate data of the source concentration in each rod. Besides verification of integrity, such data may also be used for verification of burnup and other operator-declared parameters.

2.3. Tomographic reconstructions of fuel assemblies with manipulated rods.

The removal or replacement of a fuel rod will imply a change in the measuring conditions. First of all, a change in the activity matrix will occur, which is what the tomographic measurement intends to show. However, not only the activity matrix will change, but a change may also occur to the gamma-ray attenuation matrix. This will affect the tomographic reconstruction. Two cases of manipulation can be recognised:

Replacement of a fuel rod with fresh fuel or a fuel-like material will not give rise to any changes to the attenuation matrix or only to minor changes. Tomographic reconstructions should yield the activity in such a position within the measurement accuracy.

Removal of a fuel rod, on the other hand, implies that the gamma radiation passing through that position will be less attenuated than expected from the non-manipulated fuel geometry, implying relatively larger contributions from adjacent rods to the measured intensities. Consequently, the reconstructed activity in the position of a removed rod will be finite although there is no activity in such a position. Generally, one can expect better results, i.e. a lower reconstructed activity in the position of a removed rod, when detecting higher gamma-ray energies. This is shown e.g. in ref. [4].

3. Test measurement using pool-side equipment

A test measurement on a spent fuel assembly using pool-side equipment was performed at the interim storage CLAB in Oskarshamn, Sweden, in 1996. The measurement has been elaborately reported in ref. [5] and will therefore be only briefly discussed here.

3.1. Equipment

The equipment was originally intended for gamma scanning of nuclear fuel (ref. [7]), but was rebuilt in order to perform initial tomographic tests. The equipment is illustrated in Fig. 1.

The fuel assembly was placed in a fixture to the left in the figure. It could be placed in a suitable vertical position with the aid of an elevator. The fixture could be rotated, so that the radiation field could be recorded in any selected projection angle. The detector and the collimator could be translated laterally to cover the whole projection of the assembly.

The detector used was a 40 % efficiency germanium detector with an energy resolution of 1.8 keV at a gamma-ray energy of 1332 keV. The width of the vertical collimator slit was 1 mm.

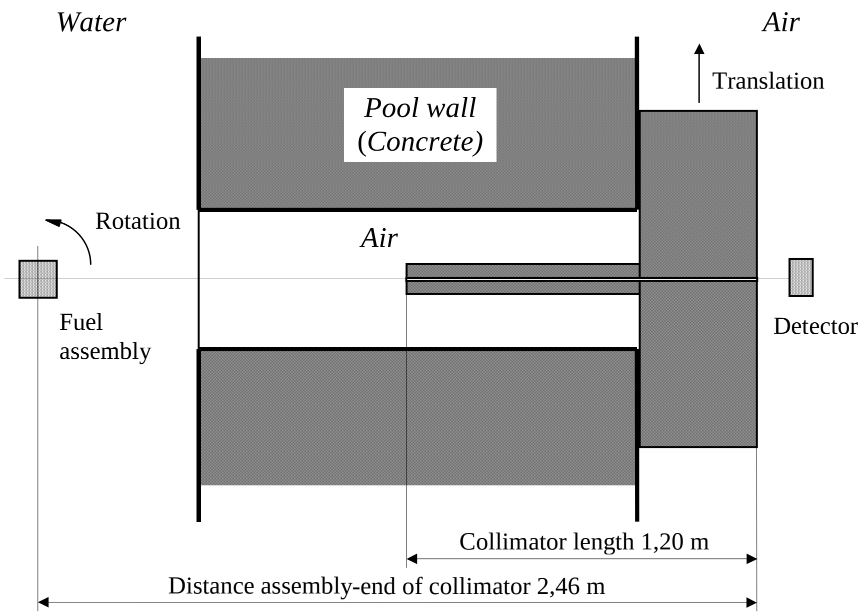

Fig. 1: Pool-side equipment. Schematic view from above.

Due to its simple design, the positioning accuracy of the test equipment was relatively poor. The estimated uncertainties were 1° in angular position and 1 mm in lateral position.

Furthermore, the fuel assembly was not firmly attached to the fixture but could move in the order of a few millimetres.

3.2. Experimental procedure

The test object was an ABB 8x8 BWR fuel assembly, normally containing 63 fuel rods and 1 water channel. A model of this fuel type is illustrated in section 4, Fig. 5. In this particular assembly the fuel rod in the central position (E,5) had been removed and replaced with an extra water channel.

The measurements took place after a cooling time of 8 years. The radiation field was recorded in 3 240 detector positions, distributed over 40 angles and 81 lateral positions. Analyses were performed using both the 662 keV gamma-ray energy of Cs-137 and the 1274 keV energy of Eu-154.

3.3. Results

The ability to detect the extra water channel in position (E,5) was investigated under the assumption that no information about the replacement was available. Only the rod-activity reconstruction technique (2) was utilised. (See section 2.2.)

Using the 662 keV gamma-ray energy of Cs-137, the activity value obtained in position (E,5), was 65% of the average rod activity. The smallest reconstructed activity of the other rods was 70%. Therefore, despite the fact that position (E,5) obtained the smallest reconstructed activity, it was not considered unambiguously distinguishable from the other rods using the Cs-137 energy.

The capability of detecting the extra water channel was improved when using the higher gamma-ray energy of Eu-154. The results using the Eu-154 energy are illustrated in Fig. 2. The reconstructed activity in position (E,5), was 59 % of the average activity. The smallest value of the normal rods was 80% of the average. The standard deviation from average of the reconstructed activities was 9.9%, position (E,5) included. The reconstructed activity in the position of the extra water channel was thus 4.2 standard deviations smaller than the average. It was clearly distinguishable from the other rods, which were all within 2.0 standard deviations from the average.

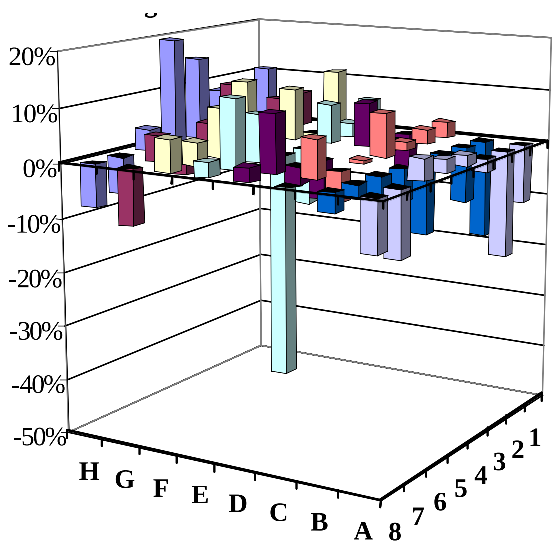

Fig. 2: The reconstructed rod activities experimentally obtained using the 1274 keV Eu-154 gamma-ray energy. Deviations from the average activity are illustrated. Note the significantly deviating value in the position of the removed rod, (E,5).

3.4. Conclusions from the test measurement

It was concluded from the test measurement that the tomographic method has a potential for partial-defect measurements, even on the single-rod level. Using the Eu-154 gamma-ray energy, the extra water channel could be clearly distinguished from the other rods. For accurate analysis of the relatively weak Eu-154 radiation in this set-up, the high energy resolution and high peak-to-Compton ratio of the germanium detector was crucial.

However, it was also concluded that the measurements would benefit from better positioning capabilities. The detector should preferably be placed closer to the assembly.

4. Laboratory measurements on a fuel model

Based on the experiences from the test measurements, a detector system suitable for in-pool measurements was conceived. The concept consisted of several Bismuth germanate (BGO) scintillation detectors in a collimator arrangement. For testing the tomographic method and, in particular, such a detector system, a mock-up for laboratory measurements was constructed.

A fuel model was built with a radioactive content of Cs-137. The main goal was to investigate the capability to make accurate tomographic measurements of the activity in each rod. To investigate the ability to perform partial-defect verification, two cases of partial defect on the single rod level were investigated; the central rod (E,5) was (1) removed and (2) replaced with a non-active rod.

4.1. Equipment

The laboratory equipment is described schematically in Fig. 3. Four BGO detectors were mounted in an iron collimator. The collimator slits were 30 mm high and widths between 1 and 3 mm were available. The slit length was 300 mm and the distance between the collimator opening and the assembly centre was 197 mm. For these measurements, a single-channel analyser was used for selecting the events in the full-energy 662-keV peak of Cs-137, as illustrated in the spectrum in Fig. 4.

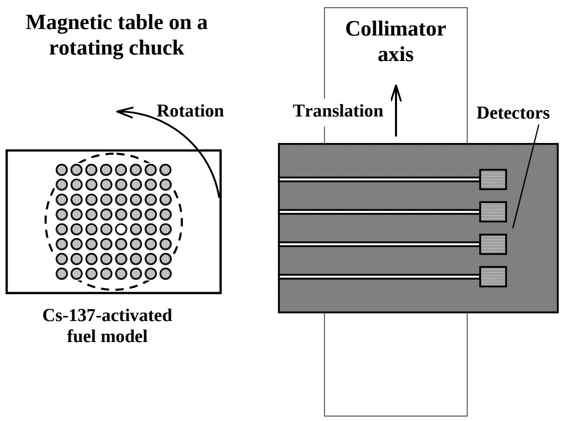

Fig. 3: Laboratory equipment. Schematic view from above.

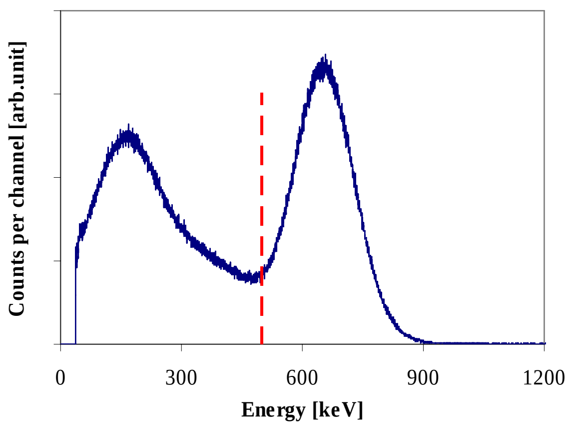

Fig. 4: Spectrum in the laboratory equipment. The applied discriminator level is illustrated.

The fuel rods were modelled using titanium tubes filled with granulated copper activated with Cs-137. These materials imply a gamma-ray attenuation roughly similar to that of Eu-154 radiation in nuclear fuel. The rods were equipped with bottom pieces of iron and could be placed in different configurations on a magnetic table.

Initially, the gamma radiation was measured from every rod separately so that their relative Cs-137 concentrations were known with 0.4% accuracy.

4.2. Experimental procedure

The rods were placed in a cross-sectional pattern similar to an ABB 8x8 BWR fuel assembly; nominally with 63 rods and a water channel, see Fig. 5. The water channel, situated in position (D,4), was modelled using an empty rod. To adapt to normal conditions in BWR fuel, the activity distribution included a tilt over the assembly. The tilt was relatively large, ranging from 25% lower to 24% higher than average. The Cs-137 distribution is presented in Fig. 5, normalised to an average activity of unity.

The ability to detect a manipulated rod in position (E,5) was investigated, both in measurements with a non-active rod in that position as well as in measurements with that position empty.

The 662-keV gamma-ray intensity was recorded in 2072 detector positions distributed over 40 angles. The slit width of the collimator was 2 mm. The measurement time in each position was 10 s, resulting in a maximum number of counts in any position of about 30 000.

4.3. Image reconstruction

Image reconstruction was performed according to method (1) in section 2.2. An image obtained in a measurement with a non-active rod in position (D,4) is shown in Fig. 6. The image reconstruction was performed based on 48x48 pixels. The whole range of reconstructed activities is covered in the figure.

It can be noted that the replacement with a non-active rod in position (E,5) is evident in the image. The empty rod in position (D,4) exhibits a higher level of noise. This is in accordance with the discussion about different manipulations in section 2.3.

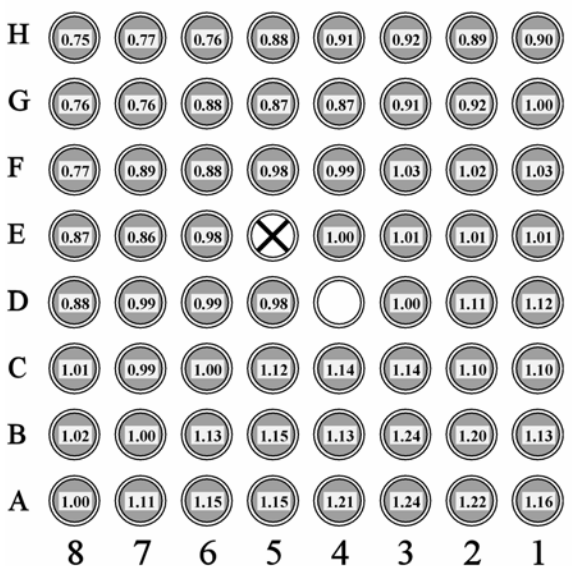

Fig. 5: The activity configuration in the laboratory model of a fuel assembly of the ABB 8x8 BWR type. The activities are normalised to a mean value of unity. Position (D,4) normally contains a water channel, which was modelled using an empty rod. The ability to detect rod removal or replacement at position (E,5) was investigated. Replacement was modelled using a non-active rod.

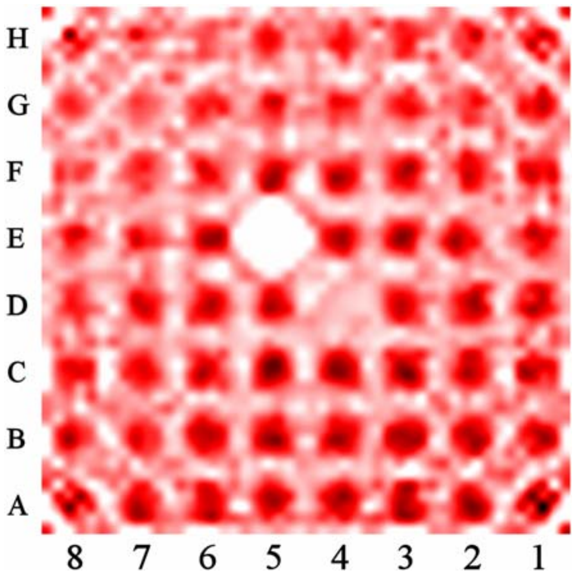

Fig. 6. Experimentally obtained image of the fuel model with a non-active rod in position (E,5) and an empty rod, representing the water channel, in position (D,4). The whole range of reconstructed activities is illustrated, where light areas illustrate low and dark areas illustrate high source concentration.

Furthermore, as seen in Fig. 6, there is a relatively high level of background noise in the image, making the fuel rods appear diffuse. A likely reason for this is the discriminator analysis of the spectra, illustrated in Fig. 4, that leads to a contribution to the recorded number of counts from scattered gamma rays. A more distinct image can be expected by performing peak analysis involving background subtraction, as demonstrated in section 5.

4.4. Reconstruction of rod activities

Reconstructions of rod activities were performed according to method (2) in section 2.2. The nominal geometry was modelled, i.e. with 63 rods and a water channel in position (D,4). The reconstructed rod activities were compared to actual activities, resulting in a relative standard deviation of 1.5%.

Two reconstructions are illustrated in Fig.7, where the central rod (E,5) had been replaced respectively removed. The results are presented as deviations from the average rod activity. The tilt of the activity distribution, as presented in Fig. 5, is clearly seen.

For the case with a non-active rod in position (E,5), the reconstructed activity in that position was 16% of the average. This should be compared with the smallest activity of the normal rods, which was 75% of the average.

For the measurement where position (E,5) was empty, the reconstructed activity in that position was 60% of the average. This was 15% smaller than the lowest activity of the normal rods. Because normal rods were measured with 1.5% accuracy (1 σ), it can be concluded that both removal and replacement are detectable with very high confidence.

4.5. Conclusions from the laboratory measurements

Rod-activity data have been obtained with 1.5% accuracy (1 σ). Such high accuracy can be valuable in terms of verifying operator-declared fuel parameters. Furthermore, both removal and replacement of a central rod have lead to significantly smaller activity values in such positions. Finally, visual inspection of presented images has offered a means for getting a quick overview of the object.

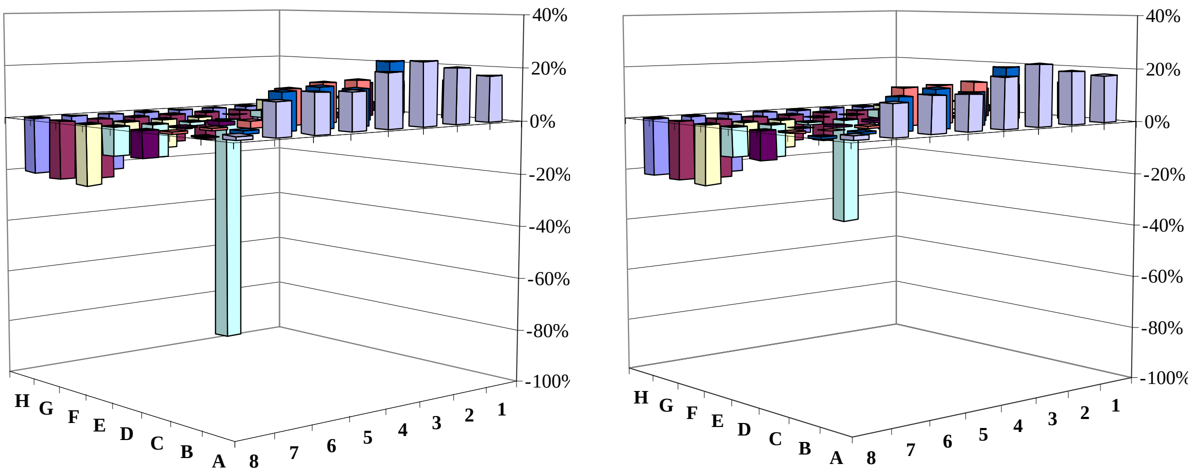

Fig. 7: Obtained deviations from the average activity in measurements using the laboratory equipment. In the left figure, rod (E,5) had been replaced with a non-active rod. In the right figure, rod (E,5) had been removed without replacement. In both cases, the value in that position is significantly smaller than the other rods. The distribution of activities in the other positions reflects the actual distribution, measured with 1.5 % accuracy (1 σ).

5. In-pool measurements

Based on experiences from the laboratory measure-ments, a device has been constructed for in-pool measurements on fuel assemblies with short cooling times (2-6 weeks). The main purpose is the deter-mination of the pin-power distribution by measuring the distribution of Ba-140, refs. [8] and [9]. However, the technique should also be applicable for measure-ments of the Cs-137 distribution in fuel with long cooling time.

Measurements have been performed at the Swedish NPP Forsmark 2. Device and measurements are more elaborately described in refs. [8] and [9].

5.1. Equipment

The device was designed for in-pool measurements. It is illustrated in Fig. 8. It has a diameter of 1.8 m, a height of 5.1 m and a dead weight of 30 metric tons. A fuel assembly is moved to the device and placed in an axial through-channel, where it is held still during the measurements, surrounded by a free flow of water.

Four detectors of the BGO scintillation type are used. These are placed in a heavy collimator made of a tungsten alloy. The device is capable of highly accurate geometric positioning along three axes; elevation, rotation and translation. The detectors can therefore be placed in different axial, angular and lateral positions relative to the measured assembly. Gamma-ray spectra are recorded using a multi-channel analyser, making spectroscopic analysis of selected full-energy peaks possible.

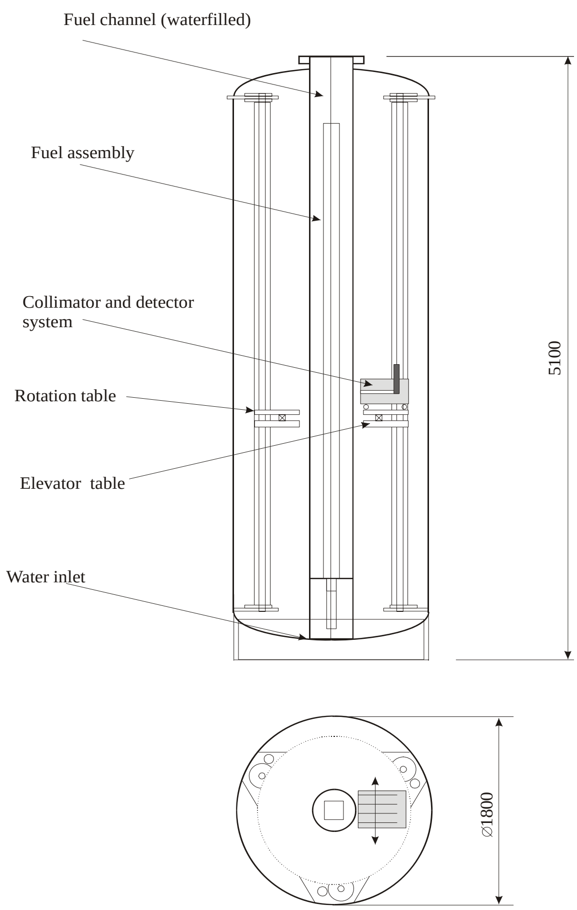

Fig. 8: Device for in-pool measurements. Schematic views from the side and from above.

5.2. Experimental procedure

The assembly selected for the measurements had been irradiated for one cycle (1 year). The measurements took place 4-5 weeks after revision shutdown. For such a short cooling time, the most suitable isotope for tomographic measurements is Ba-140. (See Table 1.)

An example of a BGO spectrum is illustrated in Fig. 9, including a spectrum collected with a 60 % efficiency Germanium detector in connection to the measurements. The spectroscopic peak analysis of the 1596-keV Ba-140 peak in the BGO spectrum is also illustrated. The Ge-detector spectrum illustrates that the Ba-140 peak is isolated in its energy range. Therefore, the relatively low energy resolution of the BGO detector is adequate.

The test object was a BWR fuel assembly of the SVEA-96S type, illustrated in Fig. 10. Measurements were performed in four axial levels. A typical data set consisted of between 3 400 and 10 200 detector positions, distributed on 85 lateral positions and between 40 and 120 angles.

5.3. Image reconstruction

A reconstructed image is shown in Fig. 10. The reconstruction was performed based upon 55x55 pixels, using the Ba-140 data measured in 10 200 detector positions. As in Fig. 6, the whole range of reconstructed values is covered.

The image clearly shows all 96 rods and the water cross separating the four sub-bundles. As compared to Fig. 6, there is a lower level of background noise in the image. This can be referred to the peak analysis performed in these measurements, which involves background subtraction and thus minimises the contribution from scattered gamma rays.

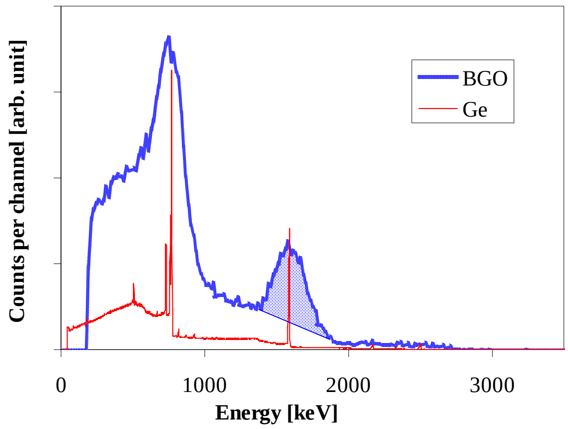

Fig. 9: A gamma-ray spectrum collected using a BGO detector and a 60 % efficiency Germanium detector. The cooling time of the assembly was four and six weeks, respectively. The peak analysis of the 1596-keV Ba-140 peak in the BGO spectrum is schematically illustrated.

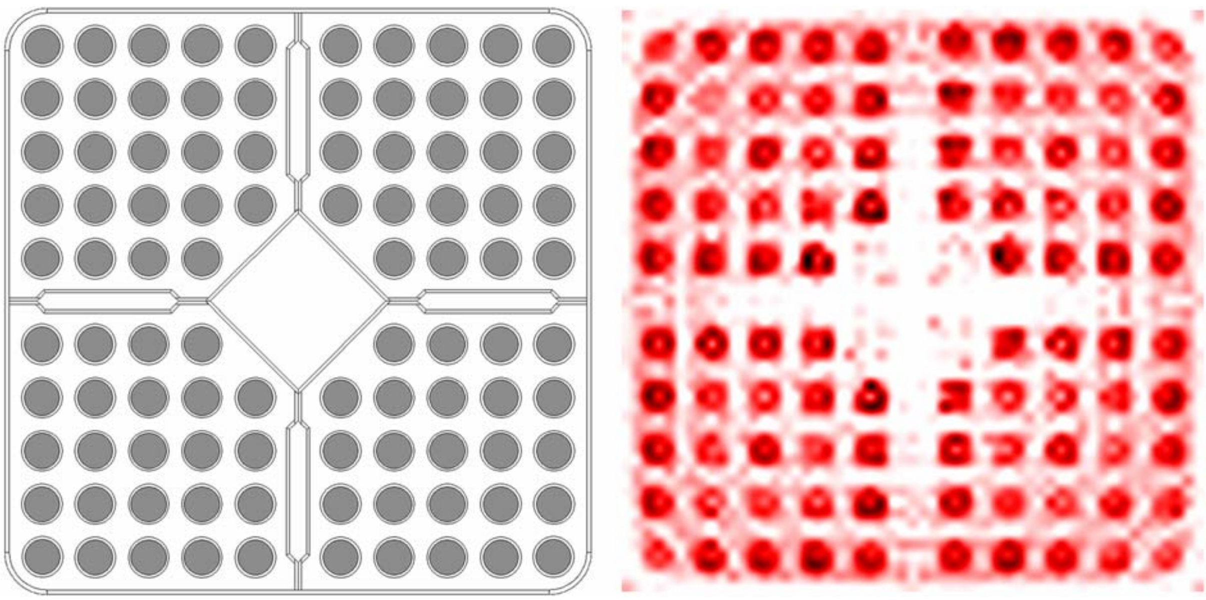

Fig. 10: The cross section of a SVEA-96S BWR fuel assembly (left) and an experimentally obtained image of the Ba-140 distribution (right). The whole range of reconstructed activities is covered. Light areas illustrate low and dark areas illustrate high source concentration.

5.4. Reconstruction of rod activities

Relative rod-by-rod activities of Ba-140 were reconstructed using method (2) of section 2.2. For comparison, the Ba-140 concentration in each rod was also calculated using the production code POLCA-7. Staff at Forsmark 2 estimated that the accuracy of these calculations was 4% (1 σ).

In all four axial levels studied, the overall agreement was within the estimated calculation accuracy. Calculated and measured distributions at axial level 23, i.e. three levels from the top of the assembly, are shown in Fig. 11. The agreement is 3.0 % (1 σ). It can be noted that the measured values for the corner rods are systematically lower than the calculated values. The reason for this is not yet fully understood.

5.5. Conclusions from the in-pool measurements

The results of the measurements were considered to be of high quality. The images obtained were distinct with low noise levels. The measured rod activities of Ba-140 agreed with calculated data within the stated accuracy of the calculations of 4 % (1 σ).

The functionality of the device was satisfying. During the measurement campaign, a fuel assembly with 4-5 weeks cooling time was placed in the equipment for almost 100 hours in total. During that time, no failures occurred.

Doses to the equipment in the range of 5-100 kGy were registered. Due to special measures taken regarding radiation shielding, no radiation damages could be observed. In measurements on fuel with a cooling time of about 40 years, as expected at the Swedish final-repository plant, such dose levels are expected after about one year of continuous exposure. This indicates that a stationary dvice, based on similar principles as the device above, can offer a high degree of availability.

In these measurements, the time required for obtaining results of satisfying quality was several hours per cross section. A new device is now planned for, where a measuring time per cross section of 20 minutes is estimated. This can be achieved by adding more detectors and improving the data-collection routines.

6. Discussion

6.1. General requirements of the equipment

The main requirements of a device for partial-defect verification are:

- Safe and practicable handling of fuel and equipment,
- confident detection of manipulated rods,
- low rate of erroneous detection,
- high availability, i.e. low failure rate,
- acceptable measurement times.

It is believed that the tomographic method can offer both highly confident detection of manipulated rods and low rate of erroneous detection. Furthermore, the in-pool measurements described in section 5 have indicated that high availability can be achieved using specially designed equipment.

	1	2	3	4	5	6	7	8	9	10
1	0.96	1.11	1.13	1.09	1.11	1.10	1.18	1.09	1.07	0.90
2	1.12	0.73	0.90	0.93	1.07	1.06	0.91	0.86	0.84	1.04
3	1.13	0.90	1.07	0.89	1.03	1.02	0.87	1.03	0.85	1.05
4	1.10	0.94	0.89	0.91	1.10	0.99	0.98	0.86	0.88	1.13
5	1.12	1.08	1.04	1.10			1.08	1.00	1.09	1.04
6	1.12	1.08	1.03	1.00			0.98	1.00	1.02	1.04
7	1.20	0.93	0.88	0.99	1.09	0.98	0.88	0.85	0.89	1.12
8	1.11	0.88	1.04	0.87	1.01	1.01	0.86	1.02	0.84	1.04
9	1.09	0.86	0.87	0.90	1.11	1.03	0.89	0.85	0.97	0.95
10	0.92	1.07	1.07	1.15	1.06	1.05	1.14	1.05	0.96	0.88

	1	2	3	4	5	6	7	8	9	10
1	0.86	1.10	1.13	1.09	1.10	1.08	1.20	1.10	1.08	0.83
2	1.11	0.69	0.91	0.95	1.10	1.09	0.89	0.88	0.86	1.05
3	1.14	0.91	1.10	0.89	1.04	1.02	0.87	1.04	0.87	1.07
4	1.10	0.93	0.88	0.91	1.11	0.93	1.00	0.86	0.91	1.17
5	1.12	1.10	1.01	1.08			1.05	1.00	1.13	1.03
6	1.12	1.08	1.04	0.96			0.96	0.98	1.04	1.02
7	1.23	0.93	0.87	1.02	1.03	0.94	0.86	0.83	0.88	1.14
8	1.12	0.89	1.10	0.84	1.03	0.99	0.85	1.03	0.82	1.04
9	1.08	0.87	0.89	0.92	1.15	1.06	0.90	0.83	0.98	0.91
10	0.87	1.09	1.13	1.20	1.08	1.07	1.18	1.05	0.91	0.78

Fig. 11: Calculated (left) and measured (right) Ba-140-distribution. The calculations were performed using the production code POLCA-7. The agreement between measured and calculated data is 3.0% (1 σ).

To be able to fulfil the main requirements, the following items have to be taken into account in the design of a tomographic device:

- Due to decay heat, the fuel has to be appropriately cooled, e.g. by having a free flow of water around the assembly.
- The distance between the assembly and the equipment should preferably be short, in order to minimise background due to gamma-ray scattering in the water around the assembly.
- Accurate geometric positioning has to be allowed for. The measurements described in section 3 indicated that it is advisable to hold the fuel assembly still during a measurement and let the equipment perform all required movements.
- The detectors have to be well shielded from background radiation using a heavy collimator. The collimator has to be dimensioned with respect to the type of fuel to be measured and the type of detectors used. The collimator's slit dimensions must allow for appropriate count rates.
- The equipment should allow for easy service and exchange of components.
- Components such as cables, motors and sensors should be shielded appropriately.

It should be noted that for a stationary device, e.g. situated at the final-repository facility planned for in Sweden, weight limitations can be relaxed to some extent. This allows for the necessary application of heavy shielding material around the detectors and other sensitive components. It may also be noted that a final-repository facility may involve more issues than verification of integrity, ref. [10]. Benefits may then be obtained if other instrumentation is combined with the tomographic device.

6.2. Requirements on the detector system

Gamma rays of certain energy should be selected in the detector/data acquisition system. The two main reasons for this are:

I. Gamma-ray attenuation has to be taken into account consistently in the tomographic procedure in order to obtain accurate results. Since the attenuation is energy-dependent, spectroscopic measurements are advantageous.
II. Different isotopes may have different distributions within the assembly. To avoid multiple components in the measured data, spectroscopic measurements should be used to select specific decays from various isotopes.

Preferably, detectors with high energy resolution, such as Ge-detectors, and high peak efficiency should be used together with spectroscopic peak analysis involving background subtraction. The main advantages of such a system would be:

- High energy resolution leads to small width of each peak. The peak of interest can be selected with high specificity. Low-level activities can be recorded in conjunction with high-level ones.
- High peak efficiency leads to large full-energy peaks and small background.
- Spectroscopic peak analysis involving background subtraction diminishes the influence of background radiation emanating from e.g. scattering.

However, depending on the spectral distribution of the object, detector materials other than Ge-detectors may be adequate. This is illustrated in Fig. 9, where the BGO scintillation detector is appropriate because the 1596 keV peak of Ba-140 is dominant in that energy region.

A comparison of the tomographic images in Figs. 6 and 10 has indicated the feasibility of spectroscopic peak analysis involving background subtraction. In the laboratory measurement, illustrated in Fig. 6, a single-channel analyser was used for selecting the events in the full-energy peak of Cs-137. In the in-pool measurement, illustrated in Fig. 10, peak analysis including background subtraction was applied to the Ba-140 peak. The latter tomographic image exhibits significantly lower background noise. The same grey-level scheme has been applied in the two images.

7. Acknowledgements

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tion of the fuel model for the laboratory measurements.

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ESARDA Activities

ESARDA NDA WORKING GROUP

RESULTS OF THE MONTE CARLO "SIMPLE CASE" BENCHMARK EXERCISE

November 2003

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1. Introduction

The ESARDA Non-Destructive Assay (NDA) Working Group (WG) has previously organised several intercomparison exercises, aimed at establishing the performance of NDA techniques currently employed in safeguards. These include round - robin exercises where laboratories make comparative NDA measurements on a set of samples, and intercomparisons for data analysis codes.

Passive and Active Neutron Coincidence Counting is widely used in safeguards for the verification of fuel pins and assemblies, the measurement of the fissile content of scrap residues from reprocessing activities, and the assay of individual fuel pellets for process control.

The use of Monte Carlo modelling is becoming increasingly widespread as a tool for reducing the reliance upon experiment (which often requires the use of costly standards) for calibration of neutron coincidence counting systems. Increasing availability of powerful computers means that the complexity with which physical systems can be modelled is increasing. However, the accuracy of the results obtained is also influenced by the nuclear data constants which are used by the program, as well as the interpretational models used to convert calculated quantities into measurement parameters. In this context, there is increasing interest in the safeguards community in establishing nuclear data sets and methodologies which can be used reliably for these applications.

The NDA WG recently published [1], the results of an Intercomparison Exercise, the "Reals benchmark exercise", in which a number of participants used MCNP™, an established Monte Carlo code in safeguards, to predict the coincidence counting rates for a standard Euratom Active Neutron Coincidence Collar. The emphasis of this exercise was placed on studying the methods used when applying MCNP™, that is, the interpretational models which are used to convert the raw calculated quantities, into quantities which are relevant to measurement, namely counting rates. To this end, participants used the same nuclear data for the actual MCNP™ runs, with a fixed, predefined geometry model, but different interpretational models. The results of comparisons with experiment demonstrated that predictions could generally be made to an accuracy of 5 - 10 %. However, due to uncertainties in the accuracy of the nuclear data constants used (neutron cross-sections, neutron source spectra, thermal neutron scattering treatments), it is not clear whether, nor by how much, it is possible to further improve on this figure, nor what are the factors which determine the fundamental limits. Furthermore, the relative contributions to the differences in results from i) differences in the nuclear data used in the interpretational models, and ii) differences in the physics of the interpretational models themselves, were not clear. Although the MCNP™ modelling was based on as accurate a geometry model as possible, certain physical effects were not taken into account, such as the true effective active length of the detectors, and the fractional wall effect losses. This means that there is an additional, as yet unquantified, source of uncertainty which undoubtedly affects the level of agreement which can generally be expected between experiment and calculation.

A new "Simple Case" benchmark Intercomparison Exercise was launched, intended to study the importance of the fundamental nuclear data constants, physics treatments and geometry model approximations, employed by Monte Carlo codes in common use. The exercise was also directed at determining the level of agreement which can be expected between measured and calculated quantities, using current state of the art modelling codes and techniques. To this end, measurements and Monte Carlo calculations of the Totals (or Gross) neutron count rates have been performed using a simple moderated ^{3}He filled cylindrical proportional counter array or "slab monitor" counting geometry. It was decided to select a very simple geometry for this exercise. This was to ensure that there is little opportunity to introduce uncertainties into the results as a consequence of errors in the geometry modelling due to the geometry being not well defined. Furthermore the use of a standard, well characterised detector system minimises the risk of introducing additional uncertainties due to errors in modelling details such as moderator density, detector fill pressures, etc. so that there is minimum potential for uncertainty due to unquantifiable variables in the geometry. The comparison between measurement and calculation was directed at the simplest possible measurable quantity, namely the Totals counting rate, in order to direct the analysis towards the influence of nuclear data, physics treatment and geometry approximations, rather than the details of a potentially complex interpretational model (the Reals Prediction benchmark focussed on this).

It was agreed that Monte Carlo modelling would be carried out by participants from as wide a range of organisations as possible. By requesting that the participants each use their preferred codes, the exercise facilitated a comparison of all the codes in common use for NDA applications in safeguards. Furthermore, the intention was for each participating group to develop their own independent geometry model, based on detailed drawings of the as – built detector system, supplied by the project co-ordinator as obtained from the manufacturers of the equipment. This gives a good overall understanding of the range of possible geometry modelling approximations and their effects. The simple geometry treated in this exercise, gives a high degree of control over the geometry variables. It was anticipated that each group would use their own preferred nuclear data sets and physics treatments, such that at the end of the exercise, analysis would allow sensitivity studies to be performed for the various factors.

By benchmarking against the experiments, it was hoped that a consensus could be reached for a preferred set of data to be used for neutron assay systems as well as providing insight into the fundamental accuracy limitations of the Monte Carlo modelling.

This report describes the scope of the measurements and calculations, and gives a summary of the results obtained (the results were presented earlier [2]). The results are compared, and sensitivity studies shown, to determine the influence of the various parameters. It is considered that this new "Simple Case Benchmark"

1 "Results of the ESARDA Reals Prediction benchmark exercise", ESARDA bulletin 31 (April 2002), pp 18 - 22. ISSN 0392-3029.

2 P M J Chard, Results of the Monte Carlo "Simple Case" Benchmark exercise, paper presented at the 25th annual ESARDA symposium on safeguards and nuclear materials management, Stockholm, Sweden, 13 – 15 May 2003, pp . EUR 20700 EN.

intercomparison exercise can potentially offer interesting and useful results to the safeguards community. The results will benefit both the NDA specialist interested in the accuracy with which Monte Carlo modelling can be used for design / calibration work and the inspector, who needs to keep up to date with the expected performance of NDA instruments and predictive tools which are increasingly being used to assist calibrations of NDA equipment.

2. Project Organisation

The project co-ordinator, Dr P.M.J.Chard of the United Kingdom Atomic Energy Authority (UKAEA), Dounreay, initially specified a simple slab geometry configuration, including various thicknesses of moderator and shielding, in conjunction with an array of ^{3}He proportional counters and a ^{252}Cf spontaneous fission neutron source. This slab monitor geometry comprised a standard “N50” neutron slab counter, as commonly used by EURATOM for monitoring Pu holdup and general monitoring of neutron radiation levels. The experiments were conducted independently of the modelling, at Harwell Laboratory, Oxfordshire, in the United Kingdom. None of the participants performing Monte Carlo modelling were given any details of the measurements, so as to ensure that the modelling was performed “blind”. Likewise, the experimenters were given no information on the modelling results, prior to completion of the measurements and assembly of the full set of the results for checking and analysis by the project co-ordinator.

A specification document was issued in order to fully describe the experimental set-up, in sufficient detail that an accurate Monte Carlo geometry model could be setup by each participant, and also to give some guidance as to the range of measurements and calculations to be performed. The various geometry configurations to be studied (additional moderator and absorber slabs) were defined in detail. This specification document was distributed for comment and finally issued for participants to commence their modelling. Following feedback from a number of the participants, clarification was given via emails to all the participants, which was subsequently incorporated into a revised version [3] of the specification document.

The specification document also gave some indications as to what nuclear data and physics treatments would be appropriate for this study. However, participants were encouraged to identify their own preferred data sets, and also to use their knowledge of alternative data sets to perform sensitivity studies in the Monte Carlo runs.

Following advertisement of the exercise, interest was expressed from various organisations, with the intention of using the most commonly used codes. In total, 10 groups participated in the modelling phase of the exercise; 7 used MCNP^{TM} while 2 used MCBEND while 1 used TRIPOLI. These participants to the exercise are summarised in Table 1. MCNP^{TM} is a modern standard code for this type of radiation transport modelling in support of the design and calibration of NDA systems for nuclear material safeguards applications. MCBEND was designed as a shielding code and, as such, has not been widely applied to NDA problems. Similarly, TRIPOLI is not widely used for safeguards / NDA applications. However, it is believed that these codes have the functionality required to perform this type of modelling.

	Group	Role
A	BNFL Instruments	MCNP 4C
B	CEA Saclay	TRIPOLI 4.3
C	CEA Cadarache	MCNP 4C2
D	RMTC IPPE	MCNP 4B
E	BNFL	MCBEND 9E (RU0)
F	NRA Argentina	MCNP 4B
G	CEN IPSN	MCNP 4B
H	Serco Assurance	MCBEND 9E (RU2)
I	IPP Obninsk	MCNP 4B
J	JRC Ispra	MCNP 4B
	Canberra - Harwell	Experiments and data analysis
	UKAEA	Project co-ordination

Table 1. Summary of participants and their roles

3 ESARDA NDA Working Group: Simple case benchmark exercise, Specification v 3.2, P M J Chard, 12/10/01.

3. Slab Monitor and detector geometry

The model N50 neutron slab monitor [4], originally designed with the aid of benchmarked MCNP™ modelling, consists of four ^{3}He detectors embedded in a polyethylene moderator. The exact details of the geometry including the detector active lengths, fill pressure, wall thickness and materials, and also the geometry and materials of the moderator and its stainless steel casing, are given in the technical specification document . Details are also given on such details as the detector dead spaces, and the dimensions of the holes into which they are embedded, so that such details could be included in the participant's Monte Carlo models. A summary of the basic N50 geometry is shown in Figure 1.

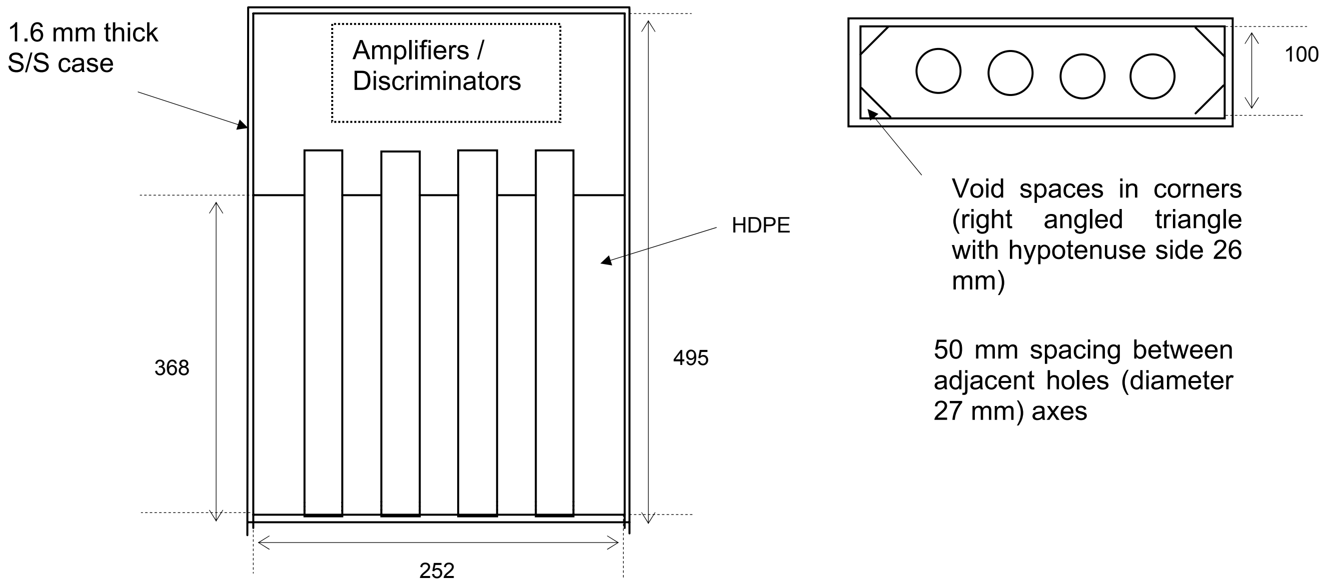


Figure 1. N50 configuration. Dimensions are given in mm.
S/S indicates stainless steel. HDPE indicates High Density Polyethylene.

3.1 Model simplifications and assumptions

The following assumptions were made by the participants, based on measured values. Full details of these can be found in the technical specification document .

- Polyethylene density best estimate of 0.94 g.cm^{-3}, based on information from the HDPE supplier.
  Note: Supplier's information indicated a possible range of densities from 0.90 – 0.97 g.cm^{-3}. The selected value is supported by a measured value of (0.95 $\pm$ 0.01) for the N50 moderator based on weight and dimension measurements allowing for "cut away" regions in the geometry.
- Detector walls Stainless Steel 7.93 g.cm^{-3}, type 347 (18 wt. % Cr, 9 wt. % Ni and 0.08 wt. % C)
- Slab casing Stainless Steel 7.93 g.cm^{-3}, type 304 (18 wt. % Cr, 10 wt. % Ni and 0.03 wt. % C)
- Cadmium metal with a density of 8.65 g.cm^{-3} and natural isotopic abundance.
- Detectors filled at 20 degrees Celcius with 4 atm. ^{3}He, equating to a fill density of 0.00050172 g.cm^{-3} (as calculated using the ideal gas law).
- ^{252}Cf source should be considered as a cylinder with outer height 10 mm, outer diameter 7.8 mm, and wall (S/S grade 347, density 7.93 g.cm^{-3}) thickness 1.6 mm. The author's direct experience shows the effect of this encapsulation on the detection efficiency is negligible (< 0.1 %), and so there is no concern over the accuracy of this part of the modelling.
- Model the system within an arbitrary 5 m radius air – filled sphere, centred at the point half way between the source and the N50 front face (on a perpendicular line). This allows for air scatter.

4 S. Croft, P.M.J. Chard, P. De Baere, D.J. Lloyd and M.T. Swinhoe. Design and performance of the model N50 neutron slab monitor system. Proceedings of the 19th ESARDA Symposium on Safeguards & Nuclear Material Management, Montpellier, France, 13-15 May 1997, pp 685 - 688. EUR 17665 EN.

- Assume that the system is neutronically isolated from the environment (most importantly the concrete floor and walls), i.e that the effects of floor / wall scatter are negligible and that they need not be included in the model. In practice the experiment was setup at the centre of a room at a large distance from the walls, and also a cadmium sheet was placed on the ground. Measurements showed that this assumption is approximately valid, and a bounding case study was performed to place an upper estimate on its effect. Experimentally this involved performing measurements as a function of source – detector separation.
- According to [5], the density of air at sea level is 0.001225 g.cm^{-3}. The composition (by volume %) of N_2 : O_2 : Ar : CO_2 : Ne : He : CH_4 : Kr : H_2 : N_2O : Xe : Rn is given as 78.09 : 20.95 : 0.93 : 0.03 : 1.8×10^{-3} : 5.2×10^{-4} : 2.0×10^{-4} : 1.0×10^{-4} : 5.0×10^{-5} : 5.0×10^{-5} : 9.0×10^{-6} : 6.0×10^{-18}.

4. Scope of measurements and calculations

4.1 Measurements

Various different states of moderation were simulated by using additional polyethylene sheets, placed both in front of, and behind (in contact with), the N50 slab. Each slab is 26.4 mm thick, the other dimensions being the same as for the N50 moderator. Configurations were also adopted with cadmium sheets (1mm thick) inserted between the polyethylene, to represent geometries with an epithermal neutron flux. In each case, the configuration of additional polyethylene / cadmium is the same on both faces of the N50. These configurations are described in Table 2.

A ^{252}Cf source was used for the present intercomparison exercise. The source spectrum from ^{252}Cf is relatively well defined and representative of fission neutrons. Furthermore, the physical dimensions of typical sources are rather small, such that the source and capsule have a negligible effect on both the spectrum of spontaneous fission neutrons emitted from the source, and the absolute neutron emission rate. A ^{252}Cf source was placed at a fixed distance of 500 mm from the front face of the slab, located about the centre of the detector array, and at the midpoint of the active length of the detectors. The slab monitor was mounted at least 1 meter from the ground, in order to minimise the contribution to the count rate from neutrons which have been in – scattered from the environment, principally the concrete floor of the laboratory. A cadmium sheet covered the floor area near the detectors, to provide further protection against re – entrant epithermal neutrons. The reference geometry should be considered as the centre point of the ^{252}Cf source capsule.

Configuration	Additional polyethylene slabs (on each face of the N50)	Cadmium sheet ?	Number of polyethylene slabs between N50 and cadmium
1	0	✗	-
2	1	✗	-
3	2	✗	-
4	3	✗	-
5	4	✗	-
6	0	✓	0
7	1	✓	0
8	2	✓	1
9	3	✓	2
10	4	✓	2

Table 2. Geometry configurations. The geometry as described is symmetric on each side of the N50.

4.2 Calculations

Calculations were performed for the 10 geometry configurations described in section 0, using a range of nuclear data options as described below. The Monte Carlo calculations were run for sufficient time to achieve a statistical standard deviation (σ) of the order 0.5 – 1.0 %, which was expected to be considerably less than the systematic differences likely to be observed during the study. As the geometry is simple and physically quite

5 R.M.Tennent (Ed.), Science Data Book, Publ. Oliver & Boyd (A division of Longman group limited), 1971, ISBN 0 05 002487 6.

compact, variance reduction techniques (which may introduce their own biases) are not required for this modelling.

The modelling also provided an opportunity to perform studies to explore the sensitivity to small geometry perturbations such as detector active length and polyethylene density. This work would be valuable in assessing the uncertainty in the performance of the detector, as a result of engineering tolerances.

5. Monte Carlo codes

MCNP™ modelling is widely used as a design / calibration tool for NDA applications in both safeguards and waste management. As well as being used as a design tool to optimise the geometry of NDA assay chambers, it can greatly reduce the amount of time – consuming experimental calibration which is required, and reduce the reliance upon physical standards. For example, MCNP™ simulations can be used to simulate the response of an NDA instrument to certain calibration sample types which are not directly amenable to experiment.

The ESARDA Reals prediction benchmark exercise [1, 6] was based on the use of the established Monte Carlo code MCNP™ [7]. This code is used for a wide range of applications in the nuclear, defence, medical, high energy physics, and industrial applications. Probably the most widely used Monte Carlo code in general use, MCNP™ has become an international standard, against which other codes are often compared. However, many other Monte Carlo codes exist, being aimed at specific application areas. For example, the Monte Carlo code MCBEND [8, 9], is aimed primarily at shielding applications, incorporating a range of physics and acceleration techniques which are tailored to these applications areas. This code is used widely in the UK for shielding calculations and assessment of radiological damage to, for example, PWR reactor pressure vessels. Similarly, the TRIPOLI [10], [11] is not widely used for safeguards / NDA applications. Although these codes have not been routinely applied to NDA applications, this is possible, and hence there is interest for the current intercomparison exercise. Since nuclear data is generally processed to provide a uniform (compatible with different operating platforms), transportable format, it is possible to use the same nuclear data (cross – sections) with different codes. This benchmark could then allow the suitability of the codes for routine safeguards NDA applications to be assessed. After a comparison has been made with MCNP™, any special features of MCBEND and TRIPOLI could be explored to determine whether there would be any useful advantage over MCNP™ in safeguards applications.

Modified versions of MCNP™ have been developed, designed to simulate the complete pulse train history in neutron counting systems, as well as performing the random walk tracking of particles in the usual fashion. These codes permit a complete simulation of the pulse train, including the arrival times of events at the detectors, allowing the prediction of coincidence count rates in typical coincidence electronics, without relying on the assumptions of the classical single point model. Two such codes are “MCNP-REN” [12] which has been

6 G. Bignan, M. Bruggeman, P. Baeten, P. Chard, S. Croft, A. Dodaro, S. Guardini, M.S.Lu, A. Mariani, S. Nonneman, D. Parker, R. Remetti and M.T. Swinhoe. ESARDA-NDA working group benchmark exercises. Proceedings of the 19th ESARDA Symposium on Safeguards & Nuclear Material Management, Montpellier, France, 13-15 May 1997, pp 505 - 518. EUR 17665 EN.

7 J.F. Briesmeister (Ed.), “MCNP - A General Monte Carlo N-Particle Transport Code, Version 4C”, LA-13709-M, Los Alamos National Laboratory, April 2000.

8 MCBEND: A Monte Carlo program for general radiation transport solutions, ANSWERS/MCBEND (94) 15, Answers Software Service, Serco Assurance.

9 G.A. Wright, E. Shutleworth, M.J. Grimstone and A.J. Bird, “The status of the General Radiation Transport code MCBEND”, Proc. 5th International Topical meeting on Industrial radiation and radioisotope measurement applications, Bologna, 2002.

10 J.P.Both, H.Derriennic, B.Morillon and J.C.Nimal, “A survey of TRIPOLI-4”, Proceedings of the 8th International conference on Radiation Shielding, Arlington, Texas, April 24-28, 1994, pp 373-377.

11 J.P.Both, Y.K.Lee, Y.Peneliau, O.Petit and B.Roesslinger, “TRIPOLI-4: Code de transport Monte Carlo – Fonctionnalites et Applications”, Societe Francaise de Radioprotection – Journees Scientifiques Francophones, Sochaux, france, October 2 - 3, 2003.

12 M.E.Abhold and M.C.Baker. MCNP-REN – A Monte Carlo tool for neutron detector design without using the point model. Proceedings of the 40th Annual Meeting of the Institute of Nuclear Materials Management (INMM), Phoenix, Arizona, July 25 – 29, 1999.

developed at the Los Alamos National Laboratory, and "MCNP-PTA" [13], developed at the Joint Research Centre (JRC), Ispra. These codes offer no advantage to the present exercise, as they are directed at simulation of the response of coincidence counters. However, these codes are also being tested for PNCC safeguards systems, and may also be studied in a future ESARDA intercomparison exercise.

6. Nuclear data

It was intended to explore the available neutron cross-section data sets which are available for use with codes such as MCNP™, MCBEND and TRIPOLI. Although the raw cross–section data evaluations for many elements / isotopes are the same across various evaluated cross-section libraries, there are differences in the data processing techniques used, in particular the fineness of the energy meshes used. Also, there are some well known changes to cross-sections which have occurred in later revisions of standard libraries, which result in more accurate data over certain energy ranges (notably, resonance regions).

Although one might expect that the latest release of a particular cross-section library (for example, the widely used ENDF-B series) should be used in all cases, this is not necessarily the case: it is possible that there may be bugs introduced into the later version. By comparing, say, the recent ENDF library releases which are in common use with MCNP™, one can assess whether there are any important differences (improvements) associated with the later releases, with regard to neutron detectors in NDA instrumentation. By comparing different evaluations, one can compare the accuracy of the benchmarking of the Monte Carlo modelling against experiment.

6.1 Cross-section libraries

Candidate cross-section libraries include (but are not necessarily limited to) the commonly available ENDF-B5, ENDF-B6, and ENDL85. The use of the $S(\alpha,\beta)$ thermal neutron scattering treatment is also of particular interest, as this is known to be important for problems involving thermal neutron transport.

6.2 Source spectra

There are several evaluations of the ^{252}Cf spontaneous fission neutron source spectrum, which will be of interest for the present intercomparison. It is thought that differences between the shapes of the low energy tail regions of the spectrum are likely to be particularly significant.

The published ^{252}Cf source spectra representations which have been identified for use here, are as follows:

1) Watt fission spectrum obtained from .

$$\chi(E) = C.e^{-\frac{E}{a}}.\sinh(bE)^{1/2}$$

where a = 1.025 MeV,
b = 2.926 MeV^{-1}

2) Maxwellian ISO standard spectrum obtained from [14] (defined in the range 100 keV – 10 MeV) and defined as a Maxwellian as follows:

$$\chi(E) = \frac{2}{\sqrt{\pi}T^{3/2}}.\sqrt{E}.e^{-E/T}.B$$

13 M. Looman, P. Peerani, P. Schillebeeckx. An Overview of NDA Instruments Modelled with the MCNP-PTA code at JRC Ispra, Proceedings of the 23rd ESARDA Symposium on Safeguards & Nuclear Material Management, Bruges, Belgium, 8-10 May 2001, pp 518 – 522. EUR 19944 EN.

14 International Standard ISO 8529 : 1989 (E). Neutron reference radiations for calibrating neutron – measuring devices used for radiation protection purposes and for determining their response as a function of neutron energy.

where T = 1.42 MeV

3) Modified Maxwellian spectrum, according to [15].
This spectrum fit is based on eight documented spectrometry measurements.
The spectrum is defined by a set of correction factors, which are applied to a reference Maxwellian:

$$\chi(E) = 0.633 CF \sqrt{E}.e^{-1.5E/2.13}$$

The correction factors (CF) are given by:

Energy range (MeV)	Correction Factor, CF
0.0 – 0.25	$1 + 1.20 \times 10^{-0.237}$
0.25 – 0.8	$1 - 0.14 \times 10^{0.098}$
0.8 – 1.5	$1 + 0.024 \times 10^{-0.0332}$
1.5 – 6.0	$1 - 0.00062 \times 10^{0.0037}$
6.0 – 20.0	$1.0 \times \exp[-0.03(10^{-6.0})/1.0]$

4) Watt spectrum fit, according to 16, from which values for a and b of 1.18 MeV and 1.03419 MeV^{-1} respectively are obtained.

In the above, E is the energy in MeV, while $\chi(E)dE$ is the proportion of the neutrons emitted in the energy increment dE about E.

7. Results

7.1 Measurements

The detection efficiency was measured for each geometry configuration, these results are summarised in Table 3. A detailed uncertainty study was performed (see Table 4) in order to assess the overall random uncertainty associated with these results.

Geometry	Efficiency (%)	1 sigma
1	2.381E-01	3.19E-03
2	2.175E-01	2.94E-03
3	1.569E-01	2.10E-03
4	1.020E-01	1.55E-03
5	6.361E-02	1.03E-03
6	2.405E-01	3.30E-03
7	1.943E-01	2.70E-03
8	1.511E-01	2.19E-03
9	1.006E-01	1.55E-03
10	6.229E-02	1.17E-03

Table 3. Measured efficiencies for configurations 1 - 10.
The 1 sigma relative standard deviation is determined from the uncertainty budget presented below.

15 J. Grundl and C. Eisenhauer. Benchmark neutron fields for reactor dosimetry. Neutron cross-sections for reactor dosimetry Vol. 1 Review Papers. Proceedings of a consultant's meeting on integral cross-section measurements in standard neutron fields for reactor dosimetry, Vienna, 15-19 Nov. 1976, IAEA-208 (Vienna, 1978) 53 – 104.

16 F.H. Froehner., Evaluation of ^{252}Cf prompt fission neutron data from 0 to 20 MeV by Watt Spectrum fit, Nucl. Sci & Eng. 106 (1990) 345 – 352.

Source of uncertainty	Relative σ (%)
Dead time losses	Negligible
^{252}Cf position	0.79
^{252}Cf source strength	0.73
^{252}Cf source anisotropy	0.40
Room Scatter	0.50
Active Length	0.12
^{3}He fill pressure	0.09
Overall	1.26

Table 4. Systematic uncertainty budget for measurements.
The σ component from random counting statistics was between ≈ 0.4 and 1.4 %, the higher uncertainties being for the more highly moderated geometries. These were added in quadrature with the overall value shown above, to produce the total uncertainties shown in the results in Table 4 and Figure 2.

The uncertainty budget presented above is based on a comprehensive analysis of all the potential uncertainties originating from the engineering tolerances in the experiment and the detector manufacture.

- The source position uncertainty arises from a combination of the uncertainty due to measurement of the source distance from the N50 slab, and the uncertainty in the exact position of the source inside the capsule. The measured variation of count rate with source - detector separation, was used to estimate the resulting uncertainty in count rate (0.79 %).
- The active length uncertainty is taken from the engineering tolerance on the anode wire length, which is 0.7 mm. This leads to a combined 1σ uncertainty for the 4 detectors, of 0.12 %. To first order, the count rate is proportional to the active length so this value can be used for the efficiency uncertainty also (in fact if the active length is large compared to the source - detector separation then the fractional efficiency increase is less than the fractional increase in active length, so this is a conservative estimate).
- The estimated uncertainty in the fill pressure is 0.14 % (0.13 % from the fill pressure and 0.03 % from the ^{3}He enrichment uncertainty), which corresponds to an uncertainty of 0.09 % in detection efficiency at 4 atmospheres (where the efficiency gain per atmosphere ^{3}He is known from experience of similar counters with different fill pressures, to be ≈ 15 %).
- The room scatter component was estimated by various methods, which all demonstrated that this is negligible at the source – detector spacing adopted. The N50 was mounted ≈ 1.6 m above the ground, and measurements with the N50 covered in Cd sheet indicated no significant difference. A power law fit to the count rate versus N50 - source separation curve, with a constant term added to allow for room scatter, suggested that the latter was close to zero, and less than ≈ 1 %. A conservative 1σ estimate of 0.5 % was thus used.

The Monte Carlo modelling methods used for this exercise assume that 100 % of the reaction products are captured in the gas, and deposit their full energy so that they appear above the discriminator threshold. In real applications, there are a number of physical reasons why this may not be exactly the case. Most importantly, wall effect losses can lead to incomplete charge deposition in the gas by one or both of the primary reaction products, if the primary event occurs near the cathode. Counting loss mechanisms such as this lead to measured detection efficiencies being lower than modelled. An estimate of the magnitude of this effect can be gained from the slope of typical counting plateaux. Typically, gradients of 1 % per 100 volts are observed, which is indicative of the counting losses due to wall effects. Further, low amplitude γ ray pileup events can sometimes give an increased signal, if the High Voltage Bias is not set to appropriately to eliminate these effects. However, usually the bias is set so that for low γ dose measurements, this is a negligible effect.

However, it is possible that this ≈ 1 % loss is partially, or more than, compensated by detector end effects. ^{3}He thermal neutron reactions within the "dead space" gas volume beneath the anode wire lower guard ring will, if the reaction products are directed vertically parallel to the anode, lead to some energy deposition in the multiplying region of the gas. Typically, the dead space represents a few % of the total detector volume, so that the corresponding increase in signal may be of the order of 1 %.

It would be of interest to perform some additional experiments / calculations to determine the magnitude of these effects. However, taking these two factors into consideration, it is considered reasonable for the present purposes to allow an additional 1 % contribution (1 σ) to the overall uncertainty. This leads to an overall systematic 1 σ uncertainty of ≈ 1.6 %, when combined in quadrature with the overall value in Table 4. This is considered to be indicative of typical uncertainties in detector geometries allowing for measurement uncertainty and engineering tolerances. It can therefore be considered as a limit to the level of agreement which can be reasonably expected, between measurement and calculation. If we allow a small contribution for counting statistics (generally several repeat runs each with a nominal precision of < 1 % were performed for each configuration), this becomes ≈ 2 %.

7.2 Monte Carlo results

The results for the different configurations, are shown in Figure 2. Since the participants used predominantly ENDF B6 cross-sections with different source spectra, the results presented here are therefore limited to the ENDF B6 data. No significant difference was observed between ENDF B5 and ENDF B6.

The results clearly demonstrate the importance of the $S(\alpha, \beta)$ treatment (group A showed that for the heavily moderated geometries, failing to use this treatment gives gross over estimates for the efficiency.). This finding is consistent with general industry experience, shared at the ESARDA NDA Working Group meetings.

The results show that there is a significant spread in the results from the various groups, of about the same order as the spread in values by varying the source spectrum alone. This is attributed primarily to differences in the modelling styles used. However, the systematic differences observed between the source spectra, are broadly consistent across the different groups. It is clear from the results that any preference towards a particular source spectrum is dependent on the state of moderation. It is interesting to note that in general the Watt (Froehner) spectrum [14] studied by three groups appears to give the minimum overall discrepancy and therefore would seem to be a good choice for general simulations. This is not necessarily the case for all geometries (for example, group E compared the Froehner spectrum with the Watt and ISO 8529 results, finding better agreement with experiment for 5 geometries, poorer in 3 cases and similar agreement in the other 2 cases) and indeed some of the better agreement could be fortuitous. However it is considered to be a good general recommendation, based on the results of the present exercise.

Group H investigated the potential benefit of the in - built variance reduction techniques in MCBEND, to reduce the run time required. It was found that by using MCBEND's automatic importance generation technique, the run time required to achieve a particular statistical figure of merit could be reduced by a factor of ≈ 3. This is interesting, and suggests that these features would be worthwhile being investigated more by Monte Carlo modellers. This would be particularly useful for modelling heavily over moderated neutron counting systems.

There is no noticeable difference in performance between MCNP™ and MCBEND or TRIPOLI. This gives confidence that these latter codes are also suitable for this type of application.

The level of agreement between calculation and experiment is summarised in Table 5. The average discrepancy is typically up to ≈ 3 %, showing a tendency to increase with state of moderation. However the spread is somewhat higher, ranging from ≈ 3 - 4 % up to ≈ 10 % for highly moderating cases. This reflects the greater effects of differences in the geometry modelling / source spectrum, for highly moderated cases in which the number of collisions is high.

Configuration	Average relative discrepancy (%)	Standard deviation of discrepancies (%)
1	-3.3	4.6
2	1.2	1.4
3	2.2	3.5
4	3.1	6.5
5	5.5	9.0
6	-4.6	4.7
7	0.0	1.7
8	0.8	3.8
9	1.4	6.8
10	2.3	9.3

Table 5. Summary of observed discrepancies between calculation and experiment.
The results for all participants using ENDF B6 have been used, excluding those without the $S(\alpha, \beta)$ treatment.

7.3 Monte Carlo sensitivity studies

Sensitivity studies have been performed to determine the sensitivity of the results to certain key geometry and nuclear data perturbations.

It was generally found that the effect of air scatter is negligible compared to the overall discrepancies observed, and thus is not critical for inclusion in the model. The effect was observed to be between 0 and 1 %, in the modelling performed. In practice, one should also consider the air humidity as this can greatly affect the hydrogen content; however this is anticipated to be difficult to quantify for general modelling applications and so is not discussed further in the context of the present exercise. Modelling a sphere of radius 5 m is assumed to be sufficient to include all orders of scatter which could potentially have a significant contribution to the result.

The sensitivity to polyethylene density has been studied in detail by group F for each configuration. In summary, the variation of efficiency with polyethylene density, exhibits a good fit to a straight line in each case. The relative % shift in efficiency per 0.01 $g.cm^{-3}$ increment is obtained from the slope of the line. The results are given in Table 6. As the uncertainty in the polyethylene density is estimated to be no more than ± 0.01 $g.cm^{-3}$, these can be used as a guide to the likely uncertainty in the efficiency. As can be seen, this ranges from ≈ 1 to 2.5 %. Groups D and H performed similar studies for configurations 1 and 5 respectively, and found results in excellent agreement with these values. Group H also demonstrated that the "first order sensitivities" perturbation method could be used in MCBEND to produce similar results, without having to repeat the Monte Carlo run with a different density value. It is possible that a better overall fit could be achieved by artificially adjusting the modelled density. However, this is just one of the sources of uncertainty and should be considered along with the other sources identified here. The purpose of the present study is to determine the overall level of agreement that can be achieved using a model which is as close to the real physical geometry, as possible.

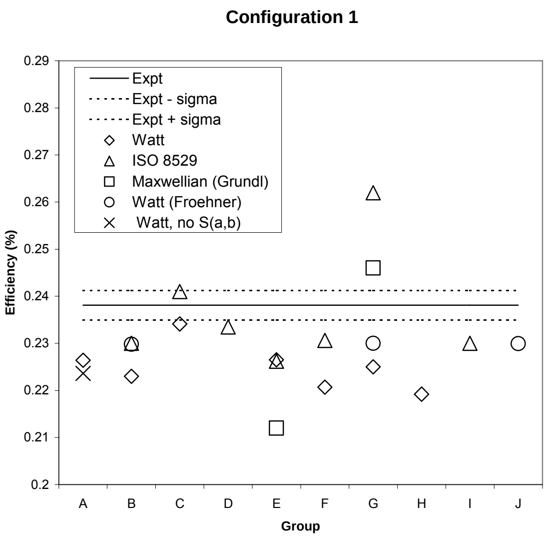
The sensitivity to changes in the diameter of the detector holes has also been studied by group F. The effect of increasing the hole diameter from 27 to 28 mm was found to be a general, relative increase in response of between 0 and ≈ 2 %. This gives an idea of the uncertainty introduced as a result of not knowing the hole diameter to absolute accuracy.

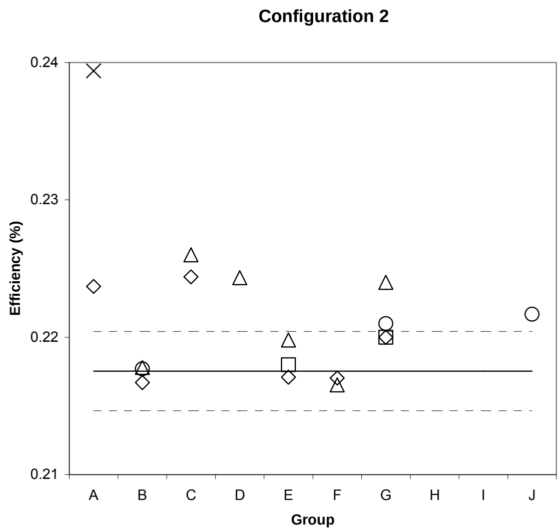
Configuration	% increase in efficiency (relative to 0.94 $g.cm^{-3}$) per 0.01 $g.cm^{-3}$ increase
1	0.73
2	-0.23
3	-1.13
4	-1.84
5	-2.45

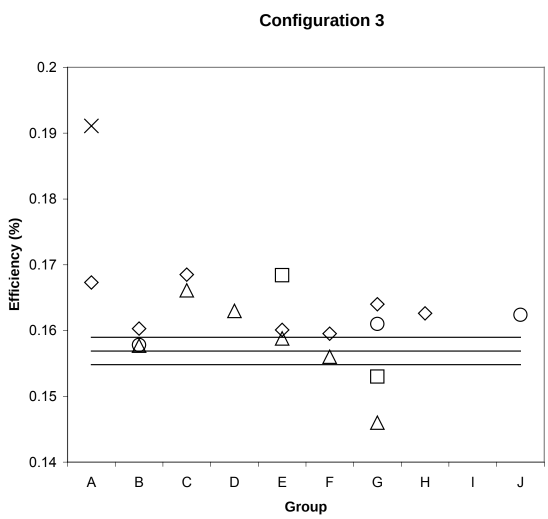
Table 6. Results of sensitivity study to polyethylene density performed by group F.

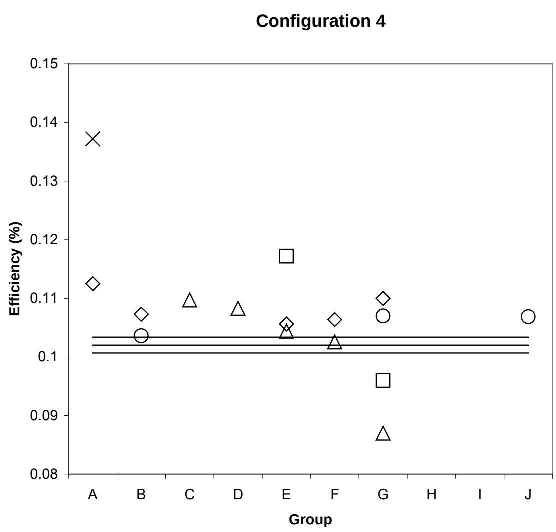
The sensitivity of response to active length was studied by group F. In fact the increase in response was found to be approximately half of the fractional increase in active length. Thus the uncertainty component assigned to the measurements (Table 4) is pessimistic.

The influence of differing neutron cross-section libraries was studied. Groups C and D found negligible difference between the ENDF B5, ENDF B6 and ENDL 85 libraries commonly available to MCNP^{TM}. Group F, however, observed little difference between ENDL85 and ENDF B5 while the ENDF B6 results were consistently lower than these, the relative difference ranging from ≈ 1 -2 % for lightly moderating geometries, up to ≈ 5 % for heavily moderated cases. The reason for this difference is not clear. However, it would be a very surprising conclusion if one were to recommend the use of anything apart from the most recent release of the ENDF B library. However, this aspect is beyond the scope of the present study and this shall not be explored further, here. It may be considered practical to use the ENDF B5 library rather then ENDF B6, since the latter does not contain cross-sections for natural elements, the natural isotopic composition having to be entered manually. However, care is required if consideration is being given to using ENDF B5 data instead of the most recent release, ENDF B6, because some data did change between these two releases (e.g. Iron).









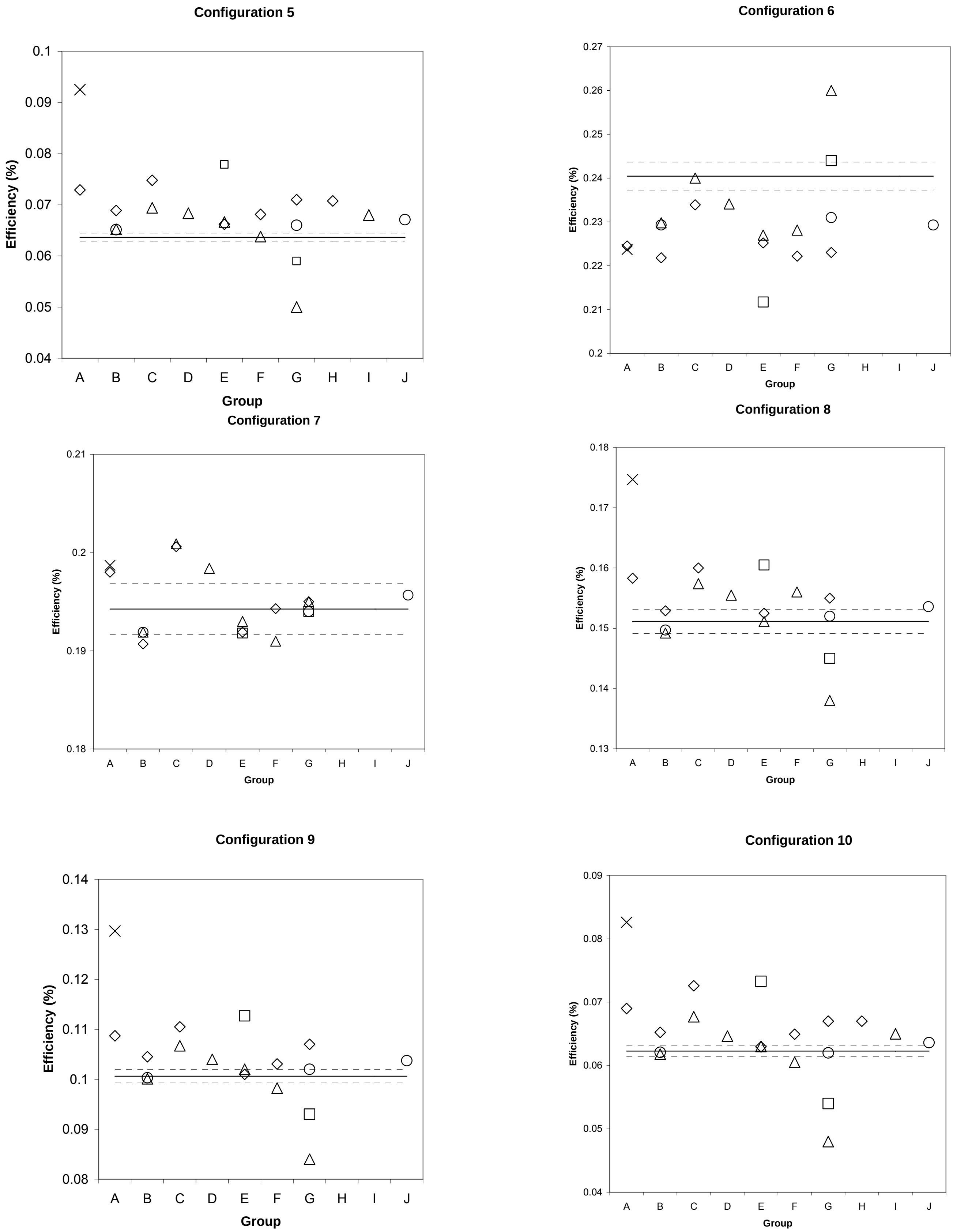


Figure 2. Comparison of calculated and measured efficiencies for the 10 geometry configurations. The calculated results shown have used predominantly ENDF B6 cross-section data sets. The measured value is shown by the solid line in each case, the dashed lines indicating 1 standard deviation limits.

8. Conclusions

The exercise has demonstrated that Monte Carlo modelling can be used to predict the Totals counting rate for a simple neutron counting geometry, to a typical level of agreement (with measurement) of ≈ 5 %, for typical lightly moderated geometries. The spread of results according to different nuclear data (principally the neutron source spectrum) and modelling styles, is also of the order of a few %, for lightly moderated geometries. For heavily moderated geometries, however, this spread increases substantially (up to ≈ 10 %), such that the influence of the nuclear data and modelling approximations are accentuated.

MCBEND and TRIPOLI have been shown to perform equally as well as MCNP^{TM} for this generic application, and the potential significant benefits of conventional variance reduction techniques have been demonstrated, even for a simple geometry such as this.

The exercise has shown some evidence to suggest that the ^{252}Cf source Watt spectrum fit according to Froehner, is a good spectrum to be used; the typical bias being minimal.

The careful experiments and comprehensive uncertainty analysis have provided a useful insight into the fundamental physics limitations to the level of absolute agreement which can be expected between measurement and calculation. We have shown that the physics uncertainties concerning largely the physics and design of the ^{3}He detectors, lead to a minimum uncertainty (1 σ) of the order of 2 % in the efficiency for this geometry. This is largely irreducible because the source strength for instance is limited by the absolute calibration of the Manganese bath method and the knowledge of the source position is limited by the size of the inner volume of the source capsule. Furthermore, if one considers the typical uncertainties in the bulk density of polyethylene, an additional component of between ≈ 1 and 2.5 % can be expected, increasing the overall uncertainty to up to ≈ 3 %. One cannot, therefore, expect better agreement than this, no matter how carefully one measures the detector dimensions, etc. The closeness of the computed results to the measured values for this Simple case benchmark exercise, are comparable to those found in the recent Reals Prediction Exercise. The Simple case benchmark is a far simpler geometry, but a wider range of nuclear data has been studied.

Current widespread practice in Monte Carlo modelling is to artificially adjust certain key parameters in the geometry model (such as the polyethylene density), in order to force very close agreement with a benchmark measurement geometry. This approach recognises the fundamental limitations posed by the uncertainties in geometry and nuclear data such as have been highlighted in this paper. It allows future studies to be directed at complex geometries such as those containing multiplying assemblies of fissile material, for which the quality of the assumed nuclear data such as the prompt and induced fission neutron multiplicity moments, is of interest.

Striving for Quality in Nuclear Analytical Laboratories

Summary of a dedicated meeting of the ESARDA DA Working Group,
27 November 2003, Geel

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Abstract

The ESARDA DA Working Group undertook to review the experience gained in the implementation and operation of Quality Assurance (QA) systems in nuclear analytical laboratories.
The scope of activities of the individual laboratory, the operational environment and the customer requirements directly affect the design of a QA system. Based upon previous experience, many laboratories now tend to intro-duce “lighter” systems, i.e. reducing the amount of documentation produced. The costs of implementation and operation are difficult to quantify; the effort is estimated to consume some 20% of the available manpower in the initial phase and reduce to 5% in the operational phase.
The group regards particularly the implementation of ISO 17025 as very beneficial to nuclear analytical laboratories. Internal and external quality control are an essential part of the quality policy in an analytical laboratory as they demonstrate the reliability of the measurement results.

1. Introduction

Analytical measurements performed on nuclear material may serve different purposes: ensure that products meet the required specifications, control of the production process, establish a material accountancy, verification of declared amounts of nuclear material, detection of undeclared activities, etc. Undoubtedly, quality in analytical measurements is essential if the objectives of the measurements are to be achieved successfully. It is, however, necessary to recognise that there are different aspects of quality. These are basically covered by the sheer measurement quality (i. e. precision and accuracy of results) and by more formal quality management systems like ISO 9000, EN 45001 or GLP (Good Laboratory Practice).

The ESARDA Working Group on Standards and Techniques for Destructive Analysis held a meeting in order to review the status of implementation of quality management (QM) systems, exchange experience with QM in the individual laboratories, examine the different approaches and illuminate the role of internal quality control. During the discussions it turned out that the focus of the laboratory and the nature of its activity need to be reflected in the way the QM system is designed. According to this profile we have grouped the laboratories into four categories:

1. **Service Laboratories in the nuclear industry** are high throughput laboratories with short response times, large number of parameters to be investigated, work in changing shifts, limited number of sample types. Complete procedure and working methods are defined.

2. **Service Laboratories for nuclear safeguards**
High number of samples, reasonably short response times, limited number of parameters to be investigated, limited number of sample types, possibly changing shifts, complete procedure and working methods are defined.

3. **R&D Laboratories**
Limited number of samples, changing sample types, varying analytical requests often requiring new methods to be developed

4. **Metrological Laboratories**
   Small number of samples, emphasis on accuracy rather then on throughput

2. Laboratory Specific Experience

The Working Group noted that all laboratories are actively pursuing the implementation of QM Systems. The ISO 9001 standard is generic and independent of any specific industry or economic sector, but is aimed preferentially at manufacturing and service industries. Most of the laboratories represented in the ESARDA WGDA are certified according to ISO 9001.

On its own, ISO 9001 is not sufficient to demonstrate technical competence of a measurement laboratory. For laboratories seeking third party recognition of their technical competence, accreditation according to ISO 17025 looks more appropriate. This is clearly stated in the introduction of ISO 17025: "*Certification against ISO 9001 or ISO 9002 does not of itself demonstrate the competence of the laboratory to produce technically valid data and results*". Having realised this, laboratories have achieved accreditation or are preparing for accreditation according to ISO 17025.

The Analytical Services of BNFL Sellafield are an example of a laboratory of category 1. ISO 9001 certification was achieved long time ago, furthermore a comprehensive Quality Management System according to UK national standard M10 is in place. They are accredited with 180 methods according to ISO 17025.

The IAEA's Safeguards Analytical Laboratory (SAL) and the Analytical Services at the Institute for Transuranium Elements (ITU) are examples of a category 2 laboratory. At SAL certification according to ISO 9002:1994 was achieved in 2000. Based on the operational experience, a second exercise according to ISO 9001:2000 (certification was achieved in 2003) led to a considerable reduction of documentation and increased transparency. About 30% of all measurements are presently carried out for quality control purposes.

ITU has a certification according to ISO 9001:2000, the Analytical Services section are heading for accreditation according to ISO 17025. The Standard Operation Procedures (SOP) are largely based on already accepted procedures, either ISO, ASTM, DIN or others described in the literature. Approximately 25% of all measurements serve quality control purposes.

Research and Development Laboratories, such as the Korean Atomic Energy Research Institute (KAERI) or the Measurement Methodology section at ITU may serve as examples for category 3 laboratories. Quality assurance required for analytical R&D is a combination of principles of project management and elements of quality management. The EURACHEM/CITAC document on "Quality Assurance for Research and Development and non-routine Analysis" provides useful guidance. KAERI is partially accredited according to ISO 17025. As mentioned above, ITU is certified for ISO 9001, thus providing the necessary elements of project management and quality management.

Metrological Laboratories form a particular group, due to the specificity of their activities. The New Brunswick Laboratory (NBL) meets regulatory requirements for QA, e. g. Code of Federal Regulations 10CFR830 (nuclear safety management), DOE Order 414.1A (Quality Assurance) or DOE Order 474.1A (material control and accountability). They are voluntarily following ISO 9001 and ISO 17025.

The Institute for Reference Materials and Measurements is aiming for ISO 9001 certification. The Isotope Measurements Unit is heading for accreditation to ISO 17025, although they share some conceptual concerns with NBL on the difficulty of finding capable audit organisations. For a formal accreditation according to ISO 17025 the identification of a suitable accreditation body might be difficult. As for the R&D laboratories mentioned above, the EURACHEM/CITAC guide may provide useful hints.

3. External Quality Control Programmes

For many years the Working Group has closely followed external measurement quality control programmes and encouraged nuclear analytical laboratories to participate. Participation in external QC programmes is recommended by ISO 17025. Guidelines for such external QC programmes are given in ISO guide 43-1. REIMEP (Regular European Measurement Evaluation Programme), NUSIMEP (Nuclear Signatures International Measurement Evaluation Programme), EQRAIN (Evaluation de la Qualité des Résultats d'Analyse dans l'Industrie Nucléaire) and SME (Safeguards Measurement Evaluation Programme) are to be understood

as an “interlaboratory testing schemes” as defined in section 4.3 of ISO 43-1. The status of these programmes was reviewed and the results obtained in the individual campaigns were discussed. The different programmes were seen as complementary: EQRAIN has been focused on element assay in samples of U and Pu nitrate solution; REIMEP has put emphasis in recent campaigns on isotope ratio measurements in U and Pu samples; NUSIMEP has offered campaigns for bulk analysis of environmental type samples, the forthcoming round will use synthetic urine as matrix; SME covers U and Pu materials in different forms and asks for element and isotope assay.
The Working Group encourages co-ordination between the different interlaboratory testing schemes. A REIMEP Steering Committee was established and held its first meeting during which recommendations for future rounds were elaborated. This Steering Committee is a sub-group of the ESARDA WGDA and shall meet biannually.

4. Discussion and Conclusions

The working group members noted that in most cases the implementation of a Quality Assurance System is a sheer necessity. The effort for implementation and maintenance of the system can be minimised by making use of existing accepted procedures and standards, such ISO, DIN or ASTM. However, significant additional resources are required during the implementation phase; this may consume up to 20% of the available manpower. During the operational phase some 5% are sufficient. However, there is very little experience in accurately quantifying the costs related to QA.

The amount of documentation (procedures, working instructions, standard operating procedures) produced appears to be proportional to the staff turn over. Analytical experience and training of staff are considered very important and seem not properly reflected in ISO 17025.

The working group agreed that it is worthwhile for an analytical laboratory to implement ISO 17025, irrespective of whether it operates in an industrial environment, as a service laboratory, as an analytical development laboratory or in nuclear metrology. This was seen to help increasing the efficiency and transparency within the organisation and to gain recognition from external parties.

The Impact of Integration of INFCIRC/153 and INFCIRC/540 Safeguards on the Use of Containment and Surveillance

ESARDA Working Group on Containment and Surveillance

The ESARDA Working Group on Containment and Surveillance dealt with the impact of safeguards integration on the use of C/S and came up with the following results and conclusions.

The WG notes that Integrated Safeguards (IS) is the optimum combination of all safeguards measures available to the International Atomic Energy Agency (IAEA) under Comprehensive Safeguards Agreements and Additional Protocols which achieves the maximum effectiveness and efficiency within available resources in fulfilling the Agency's right and obligation as laid down in paragraph 2 of INFCIRC/153 (corrected).

The WG further notes that the Additional Protocol enables the Agency to gain credible assurance about the absence of undeclared activities and facilities in the state. Thus, part of the diversion scenarios is covered by the conclusion from the Additional Protocol, i.e., traditional Safeguards measures can be reduced in declared facilities without loss of safeguards effectiveness. These two aspects provide the basis for the implementation of IS.

It is by now generally accepted that in facilities using less sensitive materials there is a potential for a relaxation of both safeguards parameters and traditional safeguards measures aiming, in particular, at a reduction of the on-site verification effort. Less sensitive material being not directly usable for nuclear weapons constitutes the major part of material under IAEA safeguards.

Therefore, IS Approaches have been first developed for facilities using indirect use materials, i.e., light water reactor power plants, spent fuel storage facilities, on-load fuelled reactors, and fuel fabrication plants; but also for research reactors.

The major safeguards parameters which lend themselves to reconsideration under IS are the timeliness goals and detection probabilities. The major safeguards elements which are being considered are unannounced inspections and the use of the state's system of accounting for and control of nuclear materials (SSAC). For instance, if the timeliness goal for spent fuel is extended from presently 3 months to 12 months, and the detection probability is lowered, then it is possible to significantly reduce the on-site verification effort.

Traditional safeguards basically use optical surveillance as well as sealing systems which are primarily applied in power reactor and storage facilities. Provided the inspection results are conclusive and do not indicate anomalies, these C/S measures help to reduce time consuming and labour-intensive on-site verification activities such as non-destructive assay measurements. On the other hand, also C/S measures require some effort for installation, maintenance, repair, replacement, integrity check, data retrieval and review, and, therefore, their cost effectiveness should always be assessed, in order to avoid any waste of resources.

Concentrating on C/S measures, optical surveillance requires the greatest effort on the part of the safeguards authority. Therefore, its use is being reconsidered in view of the implementation of IS in light water power reactors and spent fuel storage facilities.
The Agency's basic IS approach for light water power reactors is reducing the application of surveillance to only a temporary use during the refuelling period. However, this approach is valid only when unannounced inspections can be carried out. Other options of approaches are based on announced inspections using then TV-Systems with overwriting mode or triggering images on demand.

It is noted that unannounced inspections might not be applied in several countries. For instance, a practical reason for not implementing unannounced inspections may be the inability of a SSAC (i.e., national safeguards authority) to provide the necessary escorting of the Agency inspectors.

Temporary (i.e., portable) optical surveillance may be foreseen for periods, where the reactor core will be open for revision and refuelling. The Agency may not revise its existing optical surveillance approach in MOX-fuelled reactors. For instance, in Germany the majority of power reactors has a license for the use of MOX fuel. Finally, the Agency may apply remote monitoring to reduce on-site inspection effort.
Based on the above said it can be stated, that the scope of surveillance reduction will depend on the safeguards approach finally applied to specific types of facilities within a given state-level integration approach. It may vary from no change in the application of surveillance to no application of C/S at all. Although optical surveillance may be reduced in light water power reactors and spent fuel storage facilities, C/S measures will remain important also under IS. They have already been designed to meet the requirements of unattended and remote monitoring over extended periods of up to one year.

The basic requirement resulting from the integration would be the need to ensure a high level of reliability for unattended monitoring systems. In this connection, the smart sensor-concept will play a key role. It was first realised in the DCM 14-based digital camera, which is featured by high reliability, secured housing, high capacity local data storage, authentication, encryption (required for remote data transmission), uninterruptable power supply, and remote data retrieval capability. Safeguards data are authenticated at the sensor level and not lost in case of mains power outages.

Provided it will be possible to meet the individual data security and confidentiality requirements of states, the use of remote data transmission, e.g., of digital image surveillance data, may be a tool to enhance the technical possibilities of reducing on-site inspection effort. Therefore, remote monitoring may play a more important role in the IS System. However, its application should always be based on a comprehensive analysis of the resource implications, i.e., preceded by a cost-benefit analysis on a case-by-case basis. For the time being, the IAEA does not consider the implementation of remote system administration, to enable servicing of the system without travelling.

Finally, one aspect should not be overlooked. In case of any unresolvable inconsistency in the Agency's findings there are the requirements to re-establish the continuity-of-knowledge by verifying the nuclear material, to re-install the "old" C/S system, and to re-apply the "old" safeguards criteria. To this end, the Agency needs to have a certain stock of C/S equipment in hand which can be immediately shipped to and installed in the country where the inconsistency was not resolved.

In conclusion, generally IS will support the tendency to make extended use of unattended C/S measures to increase the efficiency, in particular, by reducing on-site inspection effort. The major features of adequate C/S measures are sufficient system reliability, data security and remote monitoring capability.

GUIDELINES FOR DEVELOPING UNATTENDED AND REMOTE MONITORING AND MEASUREMENT SYSTEMS

ESARDA Working Groups on Containment and Surveillance (C/S) and Techniques and Standards for Non Destructive Analysis (NDA)

1. INTRODUCTION

In December 2000, the ESARDA Scientific Council and Co-ordination Board (SCCB) charged the Working Groups on C/S and on NDA to collaborate in promoting technical developments.

The SCCB encouraged the Working Group on C/S to take the lead in preparing a guidelines document on comprehensive and integrated tools (e.g., integrated C/S-NDA systems) to support new safeguards requirements. This activity will meet the Working Group's objective '*To promote the technical evolution of automated and remote monitoring instrumentation needed by large, automated fuel facilities for cost effective operation, concentrating on the safeguards perspective*'. The strategy would be '*to collaborate with other Working Groups to develop guidelines*' and '*to prepare a guidelines document*'.
The Euratom Safeguards Directorate (European Commission, DG TREN-I) and the International Atomic Energy Agency (IAEA), termed the 'Inspectorates', at declared nuclear facilities, pursue the concept of substituting on-site inspection effort by unattended monitoring techniques. This concept had been proposed by the Working Group on C/S in 1992 [1] to the end of improving the cost effectiveness of routine safeguards by reducing inspection time in the field, and reduce the burden to the operators. In addition, nuclear radiation exposure of inspectors and technicians will be reduced. Another objective is improving the data collection and analysis by acquiring safeguards data in a timely manner at random or programmable time intervals.

Recent developments have allowed the Inspectorates to make wider use of NDA sensors in unattended mode, using the radiation signal to extract "quantitative" information, as it was always done for NDA instruments in attended mode: Pu-U mass, isotopic composition. In this document we define this "mode" of use of NDA sensors as measurement mode. Unattended Remote Monitoring and Measurement Systems (URMMS) in this document, therefore, comprise two categories of systems:

- Monitoring systems, whose rôle is the "classical" C/S monitoring and comprises components for image surveillance, radiation monitoring, electronic sealing and their integration in sensor networks. In these instruments radiation detectors are <u>not</u> used as measuring devices, but mainly as monitors (NDA components used in Surveillance or Monitoring mode), generally with the task to trigger an action (e.g., an alarm, a data acquisition, a camera) when the radiation level is higher than a fixed threshold and/or to count radioactive items (e.g., irradiated fuel assemblies) passing the sensor.
- The second category of URMMS has the same functions as the previous one, but, in addition, the NDA signal is used to provide (also) quantitative data, similar or identical in nature to the data that are produced by transportable, attended NDA systems, as for instance, Pu mass via neutron assay, Pu or U isotopic composition through gamma spectrometry. Several examples of this kind of "quantitative" use of NDA in URMMS, have been implemented in nuclear facilities in Europe for several years. [2,3]
  Measurement accuracy and quality control (QC) are important issues for these systems and often the geometry of the measurement head (the sensor) is strongly conditioned by factors like sample geometry, plant requirements and detection efficiency, imposing boundary conditions that require individual design.

To be acceptable for safeguards applications, both kinds of equipment have to comply with agreed standards which are addressed in this document.

In November 2000, the ESARDA Working Group on C/S discussed the IAEA's draft Essential User Requirements for Safeguards Unattended Monitoring Systems [4]. In October 2002, the NDA Working Group started to incorporate in the document the aspects of measurement mode. This paper presents the recommendations of both ESARDA Working Groups.

This document discusses first general aspects:	Chapter 2	General remarks
Then gives an overview of the guidelines:	Chapter 3	Guidelines – overview
Specific considerations follow:	Chapter 4	Guidelines – specific considerations
And finally, detailed guidelines:	Chapter 5	Guidelines – details

2. GENERAL REMARKS

The large variety of nuclear facilities to be safeguarded requires a great flexibility on the part of the Inspectorates in designing facility specific safeguards equipment systems. Secondly, electronic components have short times to obsoleteness requiring short-term replacement. Data carriers are a typical example for rapidly changing technologies. These aspects require the use of digital techniques (hardware, firmware, software) and modular hardware and software solutions for automated on-site instrumentation.

Safeguards equipment systems will be combinations of customised and commercial-off-the-shelf (COTS) components. Safeguards-specific requirements, i.e. high reliability for loss-free data acquisition and high data security, require customised solutions for hardware and firmware to be used in the sensitive parts of a safeguards system, i.e., the sensor heads. In other parts of the safeguards system the use of COTS components helps to reduce procurement costs for both hardware and software as well as costs on training and servicing.

It is expected that remote data retrieval will enhance the technical possibilities of reducing on-site inspection effort. The precondition is, however, that the retrieved data are authenticated and encrypted and can be evaluated at headquarters. Also, there must be an overall cost benefit compared to each current safeguards approach under consideration; i.e., the implementation of remote monitoring systems requires cost-benefit analyses on a case-by-case basis.

It is difficult to assess the investment costs for remote monitoring and measurement systems, as technical progress leads to new concepts and requires periodical replacement of safeguards equipment any way. Reduction of on-site inspection effort results in cost savings, whereas data communication encounters costs. Communication costs may vary significantly from one country to the other; in addition, the Inspectorates may face investment costs for communication infrastructure. Depending on the communication technique and the number of facilities involved, the Inspectorates may not be able to transmit data to the desirable extent. Regarding the use of encryption algorithms for authentication and encryption, the situation may become more favourable, as it is expected that algorithms become available free of charge. Archiving requirements as well as evaluation effort may be identical for systems with and without remote data retrieval.

Even under the provision that only remote monitoring and measurement systems are implemented which meet a certain reliability level, there may be a need for remote system access on the part of the system administrator, i.e., Inspectorates. If the Inspectorates request remote system access, e.g., for software upgrading and trouble shooting, it has to be evaluated whether security concerns can be sufficiently met. In fact, any provision of authorised remote system access incurs a non-negligible security risk, as unauthorised remote system access cannot be excluded. Furthermore, camera access potentially undermines the principle of delayed image transmission, if required by the plant operator.

For reasons of communication costs but also for technical reasons the amount of data to be handled must be kept as low as possible, i.e. only relevant data should be transmitted, archived and evaluated. Transmission times may become unacceptably long, archiving capacities extremely large, data management and evaluation very laborious, when considering a whole country. Data reduction is achieved by applying compression algorithms; e.g., image files can be reduced to about 20,000 Bytes per image*. In addition, scene change detection can help to reduce the number of relevant images. In a field trial a factor of 7 compared to time-triggered images was achieved. Furthermore, it is possible to correlate different types of data. For instance, images could be acquired only if radiation is detected, or if an electronic seal is opened.

The remote retrieval of state-of-health data will allow to monitor the performance of the safeguards systems and to initiate immediate repair and maintenance. Uninterrupted power, local buffering of data and high reliability of the sensor module provide the assurance of continuity of knowledge, while temporary outages of COTS components can be tolerated if they do not lead to data loss.

In some types of facilities inspection effort can be reduced by the facility operator performing safeguards relevant activities. For instance, transport and storage casks with spent fuel are sealed under camera surveillance using electronic seals with seal-video interfacing approved for safeguards use.

* un-compressed B/W image files may have typical sizes of about 300 kBytes per image

3. GUIDELINES – OVERVIEW

3.1 Unattended Integrated Remote Monitoring and Measurement Systems

Unattended integrated remote monitoring and measurement systems consist of sensor heads, associated electronics, data generators, a data collection system, and network interfacing equipment for remote data retrieval. This document discusses requirements related to modern unattended systems that are computer based. Some of the listed requirements may also be valid for systems that are not computer based.

3.2 Sensors and Data Generators

Both sensors with their electronics and data generators are security relevant components, as they are the sources of the safeguards data. Therefore, any unauthorised access to the sensitive parts must be prevented by containing these components in tamper-indicating housings and by restricting their servicing, repair and replacement to the Inspectorates' staff. A sensor which is mounted with its data generator in a single tamper-indicating enclosure constitutes a "smart sensor". The digital surveillance camera consisting of a low power OEM (original equipment manufacturer) CCD (charge-coupled device) camera and the digital camera module DCM 14 [5] mounted in the sealable IAEA standard camera housing has been the first example of a "smart sensor" [6].

It features loss-free data acquisition, and all acquired data are authenticated as closely as possible to the signal source. Loss-free data acquisition is based on the principle of uninterruptable powering (backup battery), sufficient local data storage, and compliance with the highest achievable reliability requirements.
Other sensors such as radiation detectors (in both monitoring and measurement modes) usually need to be physically separated from their data generators; in this case, the principle of tamper-indication must be maintained for the sensor, the signal line, and the data generator and signals from sensor to analyser and from analyser to data collection system should be authenticated.
The concept of "smart sensor" as defined above, has not been developed so far for radiation sensors: this is an area (authentication for NDA equipment, auto-authentication for radiation sensors) where R&D has to be promoted to fully use the potential of URMMS. The development of the digital unattended multi channel analyser DIUM is one step in this direction [7].

3.3 Data Collection System

The data collection system receives data from the sensors used within the same nuclear facility. It stores the data until retrieved on site by an inspector or remotely transmitted to the safeguards authorities' headquarters.
For on-site retrieval the data must be available on an exchangeable storage medium such as a digital linear tape (DLT), magneto-optical (MO) disk, recordable compact disc (CD-R) or DVD. In addition to the exchangeable storage medium, data collection systems may have other internal storage devices.
If a data collection system is interfaced to a public communication network, the data can be directly transmitted over the network to the safeguards authorities' headquarters.
The confidentiality of the collected data must be guaranteed at all times. If the data are retrieved on site, confidentiality is the responsibility of the safeguards staff member, also during transport from the facility to the headquarters. The inspector may want to transport encrypted data only (see below), in order to ensure confidentiality in case of loss of the data carrier.
If the data are remotely transmitted by means of a communication network, the confidentiality of the data must be guaranteed by means of an appropriate encryption mechanism.
The reliability of the data collection system can be guaranteed by a range of measures including one or more of the following: uninterruptable power supply, sufficient local storage to store the data from the different sensors over a longer period of time, redundancy of the system's vital components, auto-monitoring of different state-of-health parameters, transmission of state-of-health alarms.
Networked data collection systems must offer a sufficient level of security against unauthorised access.

3.4 Network Interfacing Equipment

This equipment is used to interface the data collection system to a public communication network (e.g., PSTN, ISDN, ADSL, satellite), with the aim to transmit the collected data and to give the safeguards authorities access to the system.
The following aspects are important: secure remote access to the data collection system; assurance of confidentiality of the transmitted data, if this would not yet be guaranteed by the data collection system; prevention of unauthorised access to the data collection system and integrity of the data.

3.5 Commercial-Off-The-Shelf (COTS) Components

Many system components such as data buses, communication links, microcomputers, data collection system, are not security relevant and, therefore, may be COTS products. Failures and mains power outages do not result in a loss of data. As all data processed in these components are authenticated, tampering is not possible undetected. The components could be serviced, repaired and replaced by commercial contractors.

3.6 Approval for Routine Inspection Use

Given the safeguards specific requirements outlined above, it is necessary that prior to acceptance as equipment authorised for routine inspection use the systems successfully pass the following evaluations:
- Qualification testing including radiation testing *;
- Third Party vulnerability analysis of the safety and security (e.g. authentication and encryption) methods (limited for NDA sensors) **;
- acceptance testing including usability review; and
- field testing.

4. GUIDELINES – SPECIFIC CONSIDERATIONS

4.1 Sensor level

The following aspects should be addressed:
- data authentication;
  Note: If NDA radiation monitoring sensors need to be physically separated from the data generators, then the principle of tamper-indication must be maintained for the sensor, the signal line, and the data generator, with other measures, like incorporating the three components in separate protection boxes and authenticating the signal from the sensor.
- front end data reduction including data compression, data correlation ***, and scene change detection;
- sufficient data storage capacity/data buffer;
- remote retrieval capability of data directly from the data generator; and
- uninterruptable power supply.

4.2 Data collection system level

The following aspects should be addressed:
- compatibility between devices of different origins;
- redundant data storage capacity;
- uninterruptable power supply;
- data encryption;
- remote data transmission capability out of facilities to Inspectorates‘ headquarters;
- integrated data review;
- provision for the plant operators to perform safeguards relevant activities, e.g., replacement of data carrier.

4.3 System Architecture

In April 1999, the Canadian Safeguards Support Programme to the IAEA organised the Workshop on Integration of Safeguards Equipment Systems involving developers [8]. The following design recommendations for unattended monitoring systems with remote data retrieval capability are supported:

- the systems should be built up from modules, as far as possible;
- smart sensors, components and other instruments should be interconnectable by adequate standard information exchange interfaces and should have a built-in redundancy for data buffering and power supply;

* For environmental testing the IAEA and Euratom have co-operated under the Euratom Support Programme to the IAEA at the Joint Research Centre at Ispra. For radiation testing the IAEA has co-operated with the Atominstitut in Vienna. The IAEA and Euratom have applied their “Common Qualification Test Criteria for New Safeguards Equipment”, version 2.0, January 2002.
** The DCM 14 digital camera module was evaluated by an Australian Expert Team in the frame of a joint Australian-German Support Programmes task to the IAEA.
*** i.e. external triggering, e.g., by radiation monitor or electronic seal

- there should be a wiring topology between the data generators and data collection systems;
- for the data collection system an adequate COTS operating system should be used.

4.4 Handling and Operation

Regarding the handling and operation of integrated safeguards systems, the following recommendations should apply:

- perform strong configuration controls for data security;
- perform system access controls;
- use approved encryption algorithms;
- develop/apply standardised vulnerability assessments;
- apply vulnerability assessment to entire systems, not just to the security algorithm;
- use certified copies of commercial-off-the-shelf software;
- provide implementation guidelines for TCP/IP connectivity;
- develop/apply procedures for key management related to authentication and encryption.

5. GUIDELINES - DETAILS

The following detailed recommendations are mainly derived from a draft document prepared by the International Atomic Energy Agency [4].

5.1 General Recommendations

(1) The system shall be modular in design.

(2) Meaningful information shall be stored on individual components and/or subsystems and shall be easily retrievable.

(3) The data collection system shall be based on PCs, with adequate operating system, e.g., Windows NT 4.0 or newer Windows versions, communicating over local area network using TCP/IP communication protocol.

(4) Commercial-off-the-shelf hardware and software shall be used to the maximum extent possible. Customised hardware and software shall be used for the security relevant parts, i.e. sensor heads and data generators.

(5) Any facility mains power failure and any restoration of power shall be noted in the state of health information file.

(6) The system must function in an unattended mode without servicing for at least 100 days.

(7) The sensor heads and data generators must produce authenticated data.

(8) In case of remote data retrieval the authenticated data must be encrypted.

(9) The system shall be able to monitor continually all its critical components and subsystems for operability and record all the equipment performance related events in the state of health information file.

(10) Data filtering and/or data compression shall not cause the loss of a safeguards relevant event.

(11) In an integrated system, daily time synchronisation and a common time base shall be provided for all subsystem clocks to within +/- 1s maximum drift/day.

(12) After a loss of power or other interruptions, the system shall perform an immediate synchronisation of all subsystem clocks upon return of mains power.

(13) The resolution of the system time stamp clock shall be better than the shortest data collection period or data gate.

(14) The system shall be designed to minimise power consumption.

5.2 Hardware Recommendations

(1) The measuring equipment and sensors shall be enclosed in sealable and tamper indicating housings.

(2) The surfaces of the equipment and sensor enclosures, internal and external, shall provide conclusive evidence of any tamper attempt.

(3) Measures shall be included to record securely tamper events in the state of health information file.

(4) The housings shall also be equipped to enable the application of safeguards seals.

(5) The enclosure shall be designed to protect against accidental damage of seal and seal wire (metal wire or fibre).

(6) The AC connection, the sensor input connections, and the DC external connection shall be tamper indicating.

(7) An uninterruptable power supply (UPS) shall be provided, capable of running the entire security system in the event of mains power failure for at least four hours without any performance degradation.

(8) For mains power failures longer than 4 hours and up to fourteen days the system shall be able to operate in a reduced performance mode with the following minimum features:

- all sensors including data generators are operating;
- all triggering signals are maintained;
- all collected data are locally stored in the sensor data generators;
- all non-essential functions are switched off to save power.

(9) After UPS power is depleted and upon return of mains power, the system shall restart in its normal operating configuration and data collection shall resume.

(10)The sensor head and data generator shall meet the requirements of the Euratom-IAEA document [9] for “High Class”.

(11)A removable mass storage device shall be provided so that system data, such as raw data, system and components identification data, event tables, and performance data, can be easily retrieved. The removable mass storage device shall be light, rugged and easily transportable.

(12)TCP/IP connectivity shall be the standard for connections between data acquisition systems.

(13)Data generators shall have a direct LAN (local area network) connection to the data collection system. For long distance and small data volume transfer a RS485 connection may be a potential alternative to the LAN.

(14)In case of failure of the data collection system or of the connection between the data collection system and data generators, data shall be stored locally in the data generators having a storage capacity of 100 days.

NDA sensors (when used in Measurement mode) generate usually large amounts of data (pulse trains, gamma spectra). For secure use in unattended measurement mode, to fulfil this condition (14) and other requirements, like Hardware Requirements 1,2,3,4, NDA data generators must be designed to incorporate the adequate data storage capacity.

(15)As far as feasible, the unattended monitoring system shall use the following standardized components:

- system enclosures
- uninterruptible power supply
- data collection computers
- external and internal cabling
- connectors
- cable entries
- patch panels
- breakers
- power terminators
- accessible controls
- junction boxes
- battery and battery enclosures
- detector assembly enclosures.

Details regarding these standardized components are to be provided by the inspectorates to the developer.

5.3 Software Recommendations

(1) The user software shall be designed to provide for easy operation and use by the safeguards inspector carrying out inspections in nuclear facilities.

(2) Software shall be implemented so that the system shall automatically start/restart after interruption of normal operations, such as power failures, without a need for the inspector to load/reload the operating software.

(3) Data shall be protected from loss during such interruptions.

(4) The software must have built-in diagnostics for both the software and hardware parameters. It must also include a self-monitoring feature to check the correctness of its set-up.

(5) For NDA systems in measurement mode, the system shall provide all QC information (from calibration, re-calibration, long term follow-up) that is incorporated in the procedures of use of the system.

(6) The system shall provide visual indicators that can be clearly seen at the time of servicing by the inspector as to whether an error has occurred during the unattended monitoring interval.

(7) The system shall produce a performance summary file, the contents of which can be easily viewed on the monitor screen during service. The summary file shall be created regularly (e.g. daily), and any time when requested.

(8) After the inspector has completed servicing, the system shall provide a visual indication of correct set-up to indicate that the system is fully operational. If the system is not operational, an indication of the fault shall be provided.

(9) An easy method of software verification, following repair or maintenance, shall be provided.

5.4 Data Recommendations

(1) Data must be date and time stamped by the data generators at the time of collection.

(2) Data must be retrievable on site upon demand of authorised personnel.

(3) If remote monitoring is provided, temporary storage of data in the case of transmission failure on a non-volatile, highly reliable medium is necessary. These data must be transmitted automatically to an authorised requester when communications are restored.

(4) State of health data of the monitoring system shall be stored in a non-volatile memory at selectable intervals.

(5) In case of remote monitoring, the performance summary shall be transmitted on request to an authorised requester at Headquarters.

(6) For ease of use, the reports shall be concise and unambiguous. The use of graphical methods to display information is encouraged.

(7) The data retrieved by the data collection computer shall be complete and not have any missing records.

(8) State of health data showing system status and safeguards data shall be stored simultaneously.

(9) Authentication information shall be embedded into the data record as or before it is emitted from the data generator.

5.5 Information Security Recommendations

(1) The information (messages, data, images, etc.) from which safeguards conclusions are drawn shall be independent and genuine.

(2) All safeguards relevant information, transmitted from the item under safeguards to the Inspectorate‘s review station, shall be authenticated by an approved method. Authentication of the data shall assure that genuine information is transmitted by an authorised source or device and has not been altered, removed or substituted.

(3) All software triggering signals shall be authenticated.

(4) When authentication cannot be implemented directly on a sensor, an approved physical system of tamper indication must be used between the sensor and the point at which authentication is applied.

(5) All information shall be handled in accordance with the Inspectorates‘ procedures for protection of safeguarded and other sensitive data.

(6) In case of remote transmission, data must be encrypted, with an approved encryption method, prior to leaving the facility to provide the Inspectorate and the State assurance that confidentiality is maintained. Proprietary encryption methods shall be specifically approved by the Inspectorates.

(7) Data authentication shall pass a third party vulnerability assessment.

5.6 Reliability Recommendations

(1) To the extent possible no single point failure shall cause loss of safeguards information.

(2) The point estimate MTBF shall be at least 150 months.

5.7 Documentation Recommendations

(1) Engineering drawings shall be supplied by developers to show how the equipment in a system is interconnected.

(2) Component lists must be provided showing the manufacturer and model of all components and recommended maintenance spares required by the Inspectorates.

(3) The following documentation shall be prepared by the responsible party/parties, then reviewed and approved by the Inspectorates:

- User Requirements/Specifications (prepared by Inspectorates)
- Functional Specifications
- Design Specifications
- Quality Assurance Plan
- Safety Analysis and Evaluation
- Manufacturing test programme, procedure and results
- Operating Manual including troubleshooting
- Maintenance Manual
- Software Code and Documentation
- Calibration Procedures
- Acceptance Test Plan and Procedure
- Training Manual for Inspector
- Training Manual for Technician

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In Memoriam

We are very sorry to announce that Bertrand Causse d'Agraives passed away in December 2004. He was only retired since two years.
Our colleague and friend has spent more than 30 years at the Joint Research Centre of Ispra in Italy.
After he got his degree from Ecole des Arts et Métiers in France he joined the JRC and was involved in the development of the Orgel project.
He has dedicated at the beginning of his career much effort in the development of techniques in the field of metallurgy. He was an expert in the field of metallic surface topography. In the beginning of 80's, he joined the safeguards project and more particularly the area of sealing and identification techniques.
He spent many years in the development and practical applications of ultrasonic identification and sealing techniques for LWR fuel bundles and bolt seals for spent fuel storage cans.
He defended with great conviction and enthusiasm the studies and results of his team in Europe (Kahl, Sellafield), Canada (AECL), US (Sandia NL), Japan (containers and LWR seals).
He participated in numerous international meetings of ESARDA, INMM, and at the IAEA to present the methods developed by his team and the methodologies of application. He was also an active participant in the C/S Working Group of ESARDA.
We will remember him as a colleague with a great technical expertise, great dedication to the job, and convinced of the role of R&D in the field of nuclear non proliferation.
He was a strong believer in the values of a United Europe, and at the same time very interested and proud to speak of literature and history of France, his home country.

The testimony of two colleagues

"I've been part of his team for the last 10 years of activity.
He loved what he was doing and was ready to move mountains to bring through his ideas. Who has worked with him, directly or not, know this!

When I joined the team, the other members explained to me that he needed to be always on the move.
He liked social events in order to forge a team spirit. When he was not on mission, he tried to organise at least one team lunch every month. On special occasions, like for the Christmas party, he always invited all his team in a small restaurant close to the lake. At the end of the lunch, he would sit at the piano and started to play, sometime for hours.
His flight schedules were always very difficult to follow. He tried to combine several appointments in several places. Of course, when something went wrong during the trip, it became very complicated to arrange everything! The mission office and the travel agency knew him very well for that!
Sometimes he also disappeared for several days. He was fascinated by history, literature, religions and so on. When he found a nice library or monastery with interesting books or people, he was able to stop over for several days ... and would forget to let us know what was happening!
Anyway, with all his faults and qualities, he will always remain for us a real "Monsieur".

"I met Mr. D'Agraives for the first time in 1999. I immediately felt a liking for this person. Any conversation with him guaranteed to raise great interest thanks to his love for culture, his intellectual curiosity and wide technical knowledge.
I remember him making intelligent banter in front of an audience, using the French language with great subtlety and wit, using play on words.
He was truly one of the few remaining representatives of a certain kind of the "vieille France".

News from ESARDA

CALL FOR PAPERS
29th ESARDA ANNUAL MEETING

Aix en Provence, France
22nd – 24th May, 2007

The 29th ESARDA Annual Meeting will be a symposium on “Safeguards and Nuclear Material Management”. It will be held in Aix en Provence, France, from 22nd to 24th May, 2007.

This symposium will be an opportunity for research organisations, safeguards authorities and nuclear plant operators to exchange information on new aspects of international safeguards and non-proliferation and their implications for research and development activities.
There will be a number of contributions from internationally renowned authorities. Presentation of papers coming from the new member States of the European Union is strongly encouraged.

The two following themes will give direction to the symposium:

- New verification technologies
- Future implementation of safeguards in Europe

Contributions may cover but are not necessarily limited to the following topics:

- Safeguards concepts (policies, perspectives, limitations, Strengthened and Integrated Safeguards, State and Regional Systems, Quality Assurance Approach)
- State level approach and Euratom system
- Co-operative programmes in safeguards; ESARDA
- Non-proliferation and future issues (Cut-off Treaty, CTBT and disarmament, excess materials, sub/cross-national threats, etc.)
- Synergies with other verification regimes (radiological, chemical, biological, dual use, etc.)
- Nuclear safeguards implementation: experience, evaluation; plant specific experience on techniques, inspections and operations
- Experience in the implementation of Strengthened Safeguards systems and Integrated Safeguards
- Human resources and knowledge management issues
- Measurements techniques and standards
- Containment and surveillance methods and techniques; interface between safeguards and protection methods
- Integrated measurement and monitoring systems
- Materials control and accounting, auditing and information systems
- Illicit Trafficking and borders control ,
- Export – Import control
- Applications of GPS and GIS and information security
- Data and information evaluation methodology, remote monitoring and secure data transmission

Papers will either be presented orally or in poster sessions. Authors are kindly requested to define, at the end of the abstract, a maximum of 5 keywords related to the topics of their paper, and to state whether they would like to present it orally or as a poster. Contributions must be written and presented in English. Presentations with original content on the above topics are strongly encouraged.
Authors are requested to submit the abstract(s) of their contribution(s) for reviewing by e-mail to:

L-V Bril
ESARDA Secretary
European Commission Joint Research Centre

e-mail: esarda2007@jrc.it

in the following format:

- title, author(s), affiliation;
- an abstract in English of about 300 words to be used for paper selection (maximum 1 standard page).

The authors are strongly encouraged to follow the "instructions for authors" available on the ESARDA web site for presenting abstracts and full contribution.

The deadline for submitting abstracts of contributions is:

24th November 2006

The abstracts will be the basis for accepting or rejecting contributions. The Technical Programme Committee will decide whether or not an accepted paper will be presented as an oral presentation or as a poster. Authors will be informed of their decisions by the end of February 2007. The compendium of the accepted abstracts will be available on the ESARDA website and distributed at the meeting.

Final papers / posters must be submitted on electronic support only (i.e., e-mail, CD-ROM for big files). The deadline is 11th May 2007. Authors are welcome to bring copies of their contribution(s) for distribution to participants. The proceedings will be published shortly after the meeting and a copy sent to each participant.

Adequate space can be arranged for commercial presentations / exhibitions. Please, contact directly Mr. D. Franquard from IRSN at e-mail: dominique.franquard@irsn.fr

Registration forms, a copy of the programme and further information about the meeting will be available on the ESARDA web-site in due time:

www.jrc.cec.eu.int/esarda

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Website Features

Website 'News' Section

In order to facilitate your visit in the website, a "News" section was implemented in 2005.

It intends to report on significant events within ESARDA. Important changes in the site are also advertised in the "News" section. During the last months, information about the London Symposium, about issuance of proceedings, and also about the new ESARDA data base of publications was posted in this section.

Information from ESARDA members will be welcome. Do not hesitate to communicate with the Secretariat and to send information about your organisation: new name, re-organisation, change / extension of responsibilities etc. ESARDA is also a forum where to exchange this kind of information.

Working Groups are also highly encouraged to send information about their future events (workshops) or their achievements (publications, awards, book issuance, etc.).

Restricted area

An area restricted to ESARDA participants was implemented in 2005.

It aims at providing Working Groups (and Steering Committee) with a repository of documents issued during their meetings. Members of WGs can visit this restricted area freely and accede to documents produced by other Working Groups. Observers of WG can accede to the documents of their own WG. In this way it is expected that exchange of information will be made easier and that new participants of the Working Group will find they way more easily.

How to proceed? Please make sure that your name is in the list of your Working Group that is regularly transmitted by the Chairperson to the ESARDA Secretariat. Then you will be given an access to the restricted area by the Secretariat.

Have an interesting and fruitful visit!