Laser based applications:
Existing and Future Solutions

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The IAEA continues to provide credible assurance to the international community regarding States' adherences to their safeguards obligations under the nuclear Non-Proliferation Treaty. Generally, industrial activities, including those related to the nuclear fuel cycle, are operating on increasingly larger scales involving more equipment, more nuclear material products and flows. With limited resources, it will be extremely difficult for the IAEA to match such an increased activity and it is important to address these challenges by improving and developing new techniques that will reduce the inspection implementation workload.

Design information verification (DIV) is a key inspection activity in the Department of Safeguards. In 2003 the IAEA introduced the laser-based DIV tool, named 3-Dimensional Laser Range Finder (3-DLR). The system, developed under the European Commission Support Programme, uses commercial off-the-shelf (COTS) hardware (Laser Scanner Imager 5003 from Zoller + Froehlich). A dedicated software for Safeguards' operation was developed by the European Commission to meet IAEA requirements. Although the initial version of the DIV Tool used some of the manufacturer's modules, the current version is now independent of those components and covers all the inspectors' activities, from 3-D data acquisition to database export/import, and can provide authenticated and encrypted data to address information security concerns. Four years after its initial testing, the IAEA has now commenced the evaluation of recent additional capabilities for the DIV tool. These include the proposed applications outlined in the following sections.
An outdoor version of the laser range finder (LRF) has been demonstrated, with a wider range up to 1km and the possibility to link data with a positioning / navigation system.

Both the existing and the outdoor version laser scanner can be coupled with the digital camera. The LRF and position data are then recorded from the exact same location, and the pictures can be mapped onto the 3-D model.

The following three figures illustrate this principle. The data in the example have been extracted from a demonstration performed with the Joint Research Centre (JRC), Ispra at the Vienna International Centre (VIC), IAEA Headquarters in November 2006 .

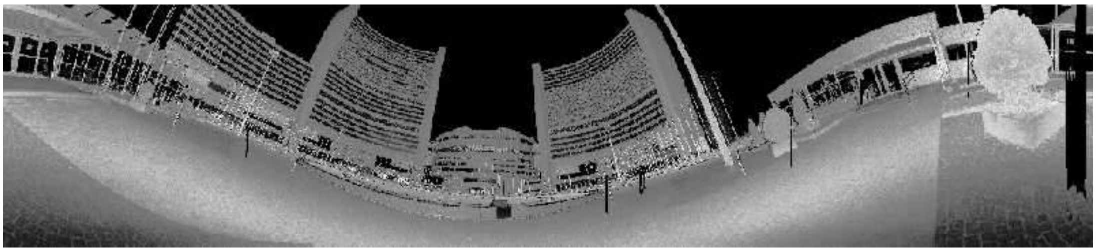


Figure 1: 3-D data acquired by the 3DLR (courtesy of EC/ JRC Ispra/ IPSC)

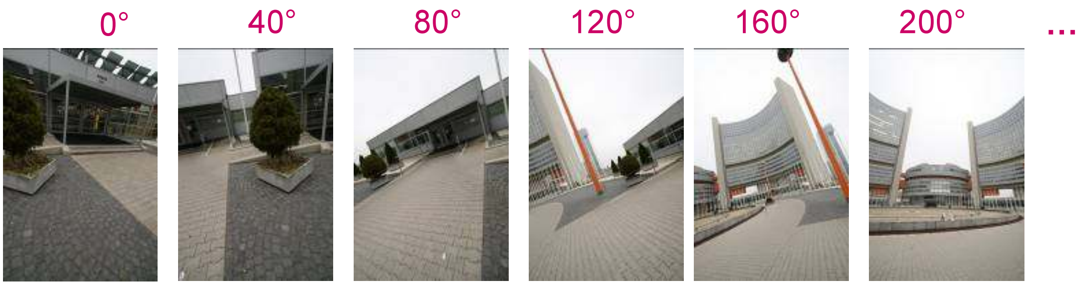


Figure 2: colour pictures taken on a 360º circumference from a common axis with the laser scanner (courtesy of the EC/ JRC Ispra/ IPSC)

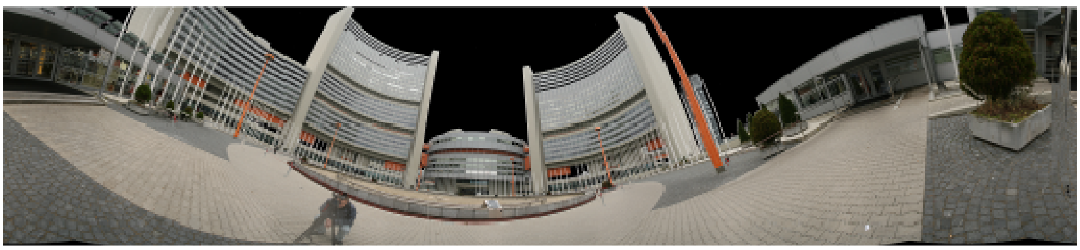


Figure 3: 3-D data + digital picture mapped in the same spatial referential. (courtesy of the EC/ JRC Ispra/ IPSC), combined results from 3-D data and colour pictures.

The obtained result provides an enriched set of data: including the high accuracy of the 3-D measurements (3-D data from the LRF), and the increase object recognition through the colour rendering provided by the photos. The rendering of the photos mapped onto the 3-D data eases the approach of the human eye, by providing colorized models.

Note that on Figure 3 *the data are presented in 2-D and therefore present a non-de-convoluted picture. This paper does not present the 3-D data, but upon request additional material could be provided.*

Another possible evolution of the 3-D LRF technique is the mapping of measurement data such as a gamma ray map. The first demonstration of this technique was organised jointly by Oak Ridge National Laboratory and Lawrence Livermore National Laboratory, and it showed the potential of mapping a wide range of data onto 3-D models. The IAEA is intending to evaluate these techniques over the coming year [1] for acquiring complementary sets of data: gamma, infra red, etc. with a strong preference for off-the-shelf equipment based projects for cost and maintenance reduction.

Laser application also applies in the domain of material accountancy in enrichment plants. Safeguards are concerned with UF_6 cylinders movement in enrichment plants. Due to the harsh environment, additional tagging of the UF_6 cylinders by IAEA inspectors was never considered a credible or cost effective possibility. Therefore the IAEA chose to use the “fingerprint” of the cylinders’ side surface to identify them. The project called Laser Item Identification System (L2IS) relies on the cylinder´s side surface that can be captured using a 3 dimensional laser surface scanning technique. The cylinder´s identity having being registered in the database, it becomes possible to verify at exit points of the process which cylinders are entering or exiting the area.

[1] First exercise is scheduled for February 2008.

The L2IS project started in November 2004 and followed the study of different technical solutions.The “Triangulation” technique, which uses off-the-shelf components, was proposed by the European Commission (EC)- Joint Research Centre (JRC) Ispra - IPSC[2], and was selected in September 2006 as the next technique to be applied. This was selected in favour of another viable technique - Laser Surface Authentication (LSA) from Ingenia, which will be discussed later in this paper.

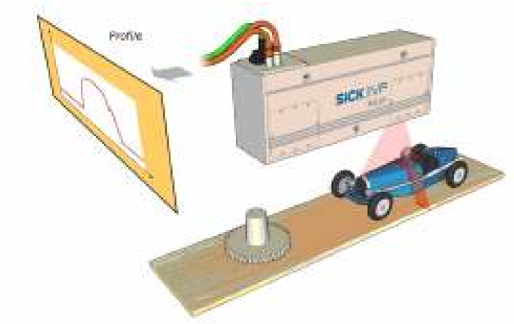
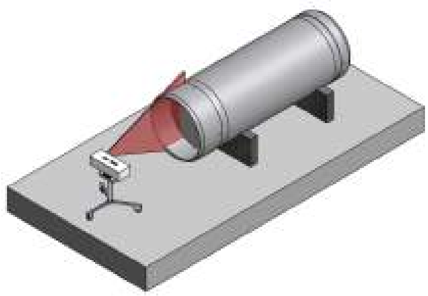


Figure 4: Triangulation concept- source SICK (Reg. Trademark) Laser Reference Manual.

The concept of the L2IS system is divided in two steps:

- **Step 1** The UF_6 cylinders that are meant to be used are made available by the operator to the IAEA inspectors for “finger print recording”

Figure 5: L2IS unit 1 concept



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The inspector uses a portable unit (see Figure 6) to acquire the cylinder identity and “populates” the so called “reference database”.

Figure 6: L2IS unit 1 scanning a 48Y cylinder: portable and operated by IAEA Staff.

[2] Institute for the Protection and Security of the Citizen (IPSC) European Commission - Joint Research Centre (JRC) Ispra – ITALY.

The cylinder's fingerprint is acquired and stored in a laptop. The laser scanner is operated on batteries, and the portable unit is mounted on wheels, enabling ease of transportation, positioning and operation in storage areas. The system geometry can also be adjusted to cope with storage configuration in addition to the different sizes and types of cylinders, including the 30B, IPC 48Z and 48Y types.

- **Step 2** The second L2IS unit (unattended) is resident in the facility and positioned at a key point. All cylinders entering and exiting the enrichment process area pass by that point and are "recorded" by the L2IS unit.
Standard surveillance is also applied at the key point to ensure the completeness of the scanning (see Figure 7). The surveillance system (standard IAEA SDIS[3]) also ensures state of health transmission on a daily basis to the IAEA office.

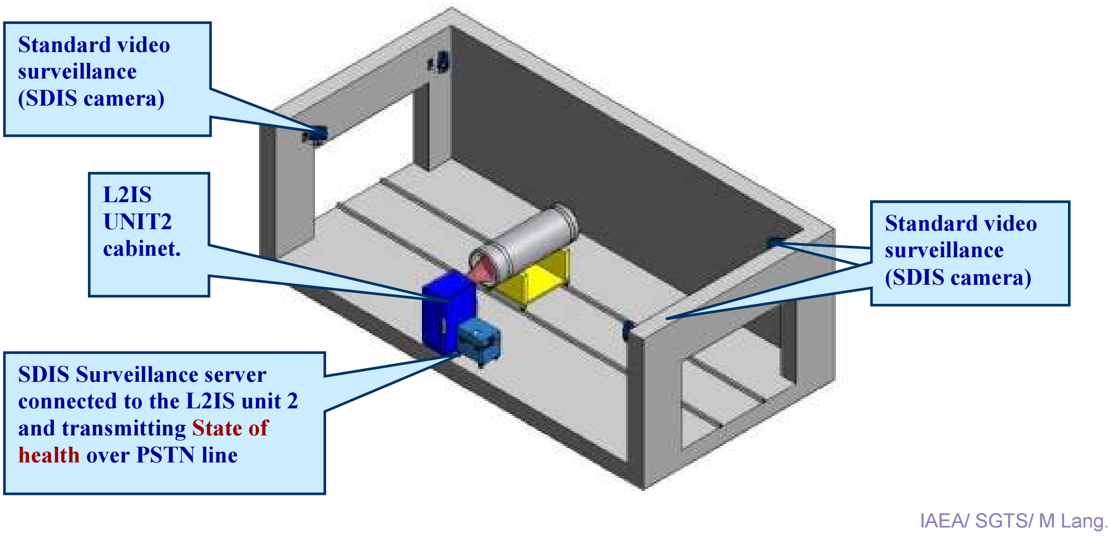

Figure 7: L2Is unit 2 concept

The installed unattended system has run without any problem to date. The L2IS data are reviewed simultaneously with the surveillance data using the IAEA GARS[4] surveillance

[3] SDIS – Server Digital Image Surveillance

review software. These various achievements clearly justify the validity and the maturity of the selected technical solution.
The L2IS system appears to be reliable and consistent with the needs specified by the IAEA. Further improvements are now under development, and they will be incorporated later this year to extend the system's functionality. The L2IS system is also of interest to other areas of the IAEA inspection work and its application is now envisaged in other enrichment plants.

In addition to monitoring the movement of safeguards relevant items, containment integrity issues of transporting packaging can be addressed with the same 3-dimensional laser surface scanning technique. This project is also developed with the technical support of the European Commission Support Programme.
The triangulation technique is used to map the entire surface of packaging containers in order to verify their integrity before, and at, the arrival of a shipment. The foreseen first application of laser surface mapping (LSM) is in Japan.

The concept of the LSM system is divided in two steps:
- **Step 1** The fuel packaging is scanned in order to acquire a complete 3-D model of the container's surface before it is shipped.
- **Step 2** The fuel packaging is randomly scanned at the receiving location(s).
In both cases the same hardware is used, and the results are relatively immediate, since the container's surface map will be stored securely in the acquisition laptop.

In the area of containment, a similar laser-based application is under evaluation for enhanced metal seal verification methods. This new method is based on the laser surface authentication (LSA) technique developed by Ingenia (LSA®-U.K). The LSA technique was first evaluated in the UF_6 cylinder identification project, but was not selected as the proximity of the laser to the cylinder being scanned was too close for UF_6 cylinders (too much constraint on the field system and the operator). The evaluation of the LSA demonstrated the technique's suitability for metal seal verification.

[4] GARS – General Advanced Review Station

The technique relies on the laser beam producing speckled light from the microscopic surface finish, which in turn creates a the fingerprint of the surface.

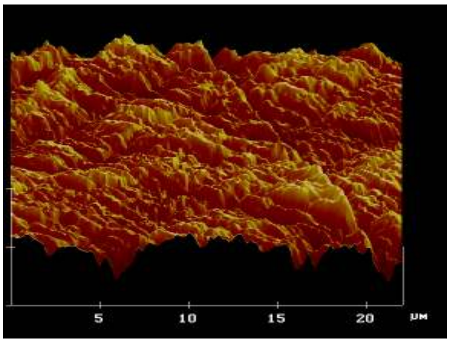

Figure 8: Surface Roughness at Laser Wavelength Scales - Photo Courtesy of Ingenia Technologies Limited.

Obtaining such accurate fingerprints of the IAEA metal seals provides a number of operational advantages, including the following:

- mapping of the metal seals surface before use provides an accurate reference for subsequent verification,
- the storage of accurate digital data provides the possibility of automating seals verification when the seal is returned to Headquarters, and
- eventual on-site verification capability.

The IAEA uses an average of 20 000 metal seals per year. Therefore, improvement in the integrity and readability of metal seals will greatly improve the overall cost-effectiveness of seals and seal verification:

- low cost for initial recording and final verification,
- small amount of data per seal,
- counterfeit resistant signature of the seal, which does not require any mechanical work.

Another laser-based project also under evaluation is tunable diode laser spectroscopy (TDLS). This technique offers the possibility of performing measurements of UF_6 at enrichment facilities such as: on-site ambient air monitoring for HF traces detection, destructive analysis of UF_6 samples, on-line enrichment and flow monitoring.

0These include the following:

- Accurate UF_6 enrichment measurement for bias defect analysis in the frame of material balance verification,
- Verification of shutdown state at a facility.

The TDLS project is part of the "**Techniques and Equipment for Safeguards at Gas Centrifuge Enrichment Plants"** project[5] that was established by the in the IAEA in 2007, in order to develop an improved set of instruments to better support verification at enrichment facilities. The project is managed by the IAEA, with technical support from Canberra-Albuquerque, USA , the German support program and the Kurchatov Institute of Moscow.

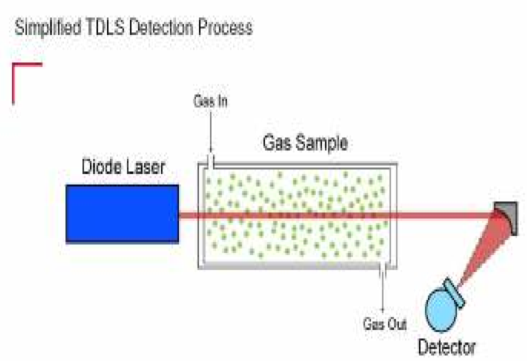

Figure 9: Simplified TDLS concept

The technique uses a diode laser with a tunable wavelength to scan the relevant absorption bands. There have been a number of challenges with the development of TDLS technique, including:

- Requirements for an extreme level of equipment stability,
- Requirements for highly accurate and stable laser temperature control.

As with all IAEA safeguard equipment, it should be simple to learn and to operate and feature strong safety requirements inherent to the operation of lasers. Due to its specialized application, the system is not commercially available, requiring that it be developed and specifically built to meet IAEA safeguards needs. The IAEA's Member State Support Programmes will also play an essential role in the success of such a project,

[5] Project for improving techniques and instruments within the Department of Safeguards for implementation of the IAEA safeguards at enrichment plants. It has been produced in compliance with the IAEA Safeguards strategic objectives 2006–2011 and Strategic Equipment and Technology Development Plan for 2006–11.

regarding funding, development and testing of the equipment. The TDLS system will also have to be evaluated against other techniques (existing or under development) in order to fully gauge its effectiveness.

Within the scope of novel technologies, the light detection and ranging (LIDAR) technique promises the possibility of detecting the presence, and /or nature of a nuclear process from a remote location up to 10kms from the emanating source.

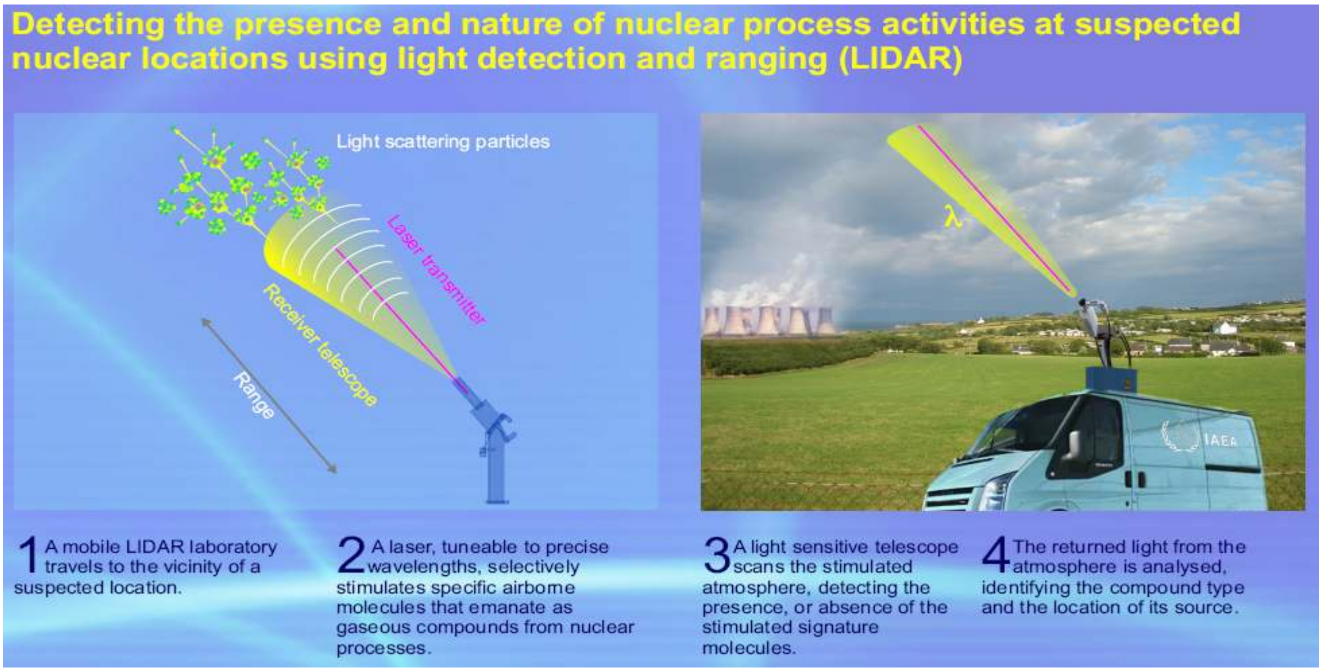

Figure 10: LIDAR concept

The LIDAR technique is currently under consideration by the IAEA as a part of its project investigating novel techniques and instruments for detection of undeclared nuclear facilities, materials and activities. The project was established as an outcome of the 2004 IAEA General Conference and specifically aims at the following objectives:

- Monitor and address observed deficiencies or vulnerabilities in safeguards approaches, equipment and technology,
- acquire new, or improved, equipment / technology where appropriate ,
- develop and/or use new concepts, approaches, techniques and technology for

information analysis and verification activities (especially with regard to an enhanced capability of detecting undeclared nuclear material and activities).

In early 2005, the IAEA requested Member State Support Programmes to propose novel technologies that would be useful for the detection of undeclared activities. Relevant technical proposals were prioritized and LIDAR is an outcome of that process.

The Agency requires the ability to detect, from a distance, indicators and signatures originating from nuclear activities. LIDAR systems are powerful tools for remote sensing of atmospheric toxic gaseous species, and the technique is used widely around the world by environmental agencies for the detection and measurement of airborne pollutants. Nuclear activities, such as uranium enrichment, operation of nuclear reactors and fuel reprocessing, can release specific pollutants into the atmosphere that can be detected using LIDAR systems from a distance of some kilometres. Pollutants can be used to detect specific signatures from some nuclear activities, hence making it useful for the detection and identification of undeclared facilities and activities. The required system will be mobile and capable of being shipped on a transport vehicle. This mobility will optimize the sampling position depending on the geographical configuration of the site and the weather conditions.
Whether the applications are in the surveillance, containment or non-or destructive assay, laser based applications are opening new possibilities by improving existing tools and methods, or proposing new tools.

Most of these new applications are supported by the Member States Support Programmes, either for development, funding, procurement of the equipment, expertise, or the provision of field testing facilities. The IAEA is looking ahead and needs assistance from the support programs more than ever, to improve and develop the previously quoted projects but also to further develop new projects.

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