The Canadian Safeguards Support Program Sponsored Projects on New/Novel Technologies: Update

R. Kosierb
Canadian Nuclear Safety Commission (CNSC), Ottawa, Canada, K1P 5S9
Email: Rick.Kosierb@cnsc-ccsn.gc.ca

Abstract: Two novel developments the Canadian Safeguards Support Program (CSSP) is pursuing are the use of lasers in breakdown spectroscopy (LIBS) and optically stimulated luminescence (OSL). These are recently proven technologies used within industry. The CSSP is examining their employmnet possibility by the IAEA. Both of these technologies appear to have the potential of being used both in facility and field operations to detect nuclear clandestine activities and thereby monitoring and reducing the number of environmental samples taken by the IAEA. This briefing provides an update on the progress in these areas as well as discussing devlopments in the use of Fourier transform infrared (FTIR) radiometry and a recent major equipment enhancement for the IAEA in their use of the Digital Cerenkov Viewing Device (DCVD).

Introduction

In 2005, the International Atomic Energy Agency (IAEA) began the process of obtaining States' aid in determining and/or developing new or novel technologies in their endeavour of detecting clandestine nuclear activities, as per their Director General's address at the 2004 General Conference. The Canadian Safeguards Support Program (CSSP) accepted this task and proposed 6 different technologies being developed within Canada. 2 were accepted: Laser Induced Breakdown Spectroscopy (LIBS) and Optically Stimulated Luminescence (OSL). Since this acceptance, the CSSP has been pursuing these technologies with its fellow Government organizations and contractors. An understanding of how LIBS, OSL and 2 other technologies are being adapted to meet the IAEA's needs follows.

Laser Induced Breakdown Spectroscopy (LIBS)

The LIBS technique is an attractive method for the IAEA in that it can quickly detect, identify and quantify the chemical composition of any material in any form (e.g. gas, liquid, solid, conductive or non-conductive). Using a high-powered pulsed laser, the beam is focused just below the surface of the object to be analyzed, Figure 1. Plasma (ionized gas) is produced consisting of the

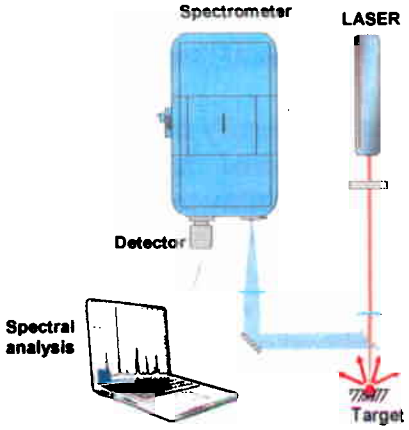


Figure 1: LIBS Schematic

target's elemental composition. The light emitted by the plasma is collected through an optical fiber cable into a spectrometer equipped with an Intensified Charge Coupling Device (ICCD) camera. Within the spectrometer, the white light is separated into the various wavelengths and detected by the ICCD camera to produce a LIBS spectrum. Chemometrics is employed to segregate, identify and quantitatively analyze the spectrum.

Figure 2 presents the spectra for 5 major alloys. A quick visual examination can identify significant differences between these metals. The chemometric method readily sorts through a library of reference LIBS spectra to identify the class of material, Figure 3. A further analysis can discriminate the material into sub-classes, such as pure iron, maraging steel, different zirconium alloys, etc. The limiting factor is the amount of reference spectra within the library.

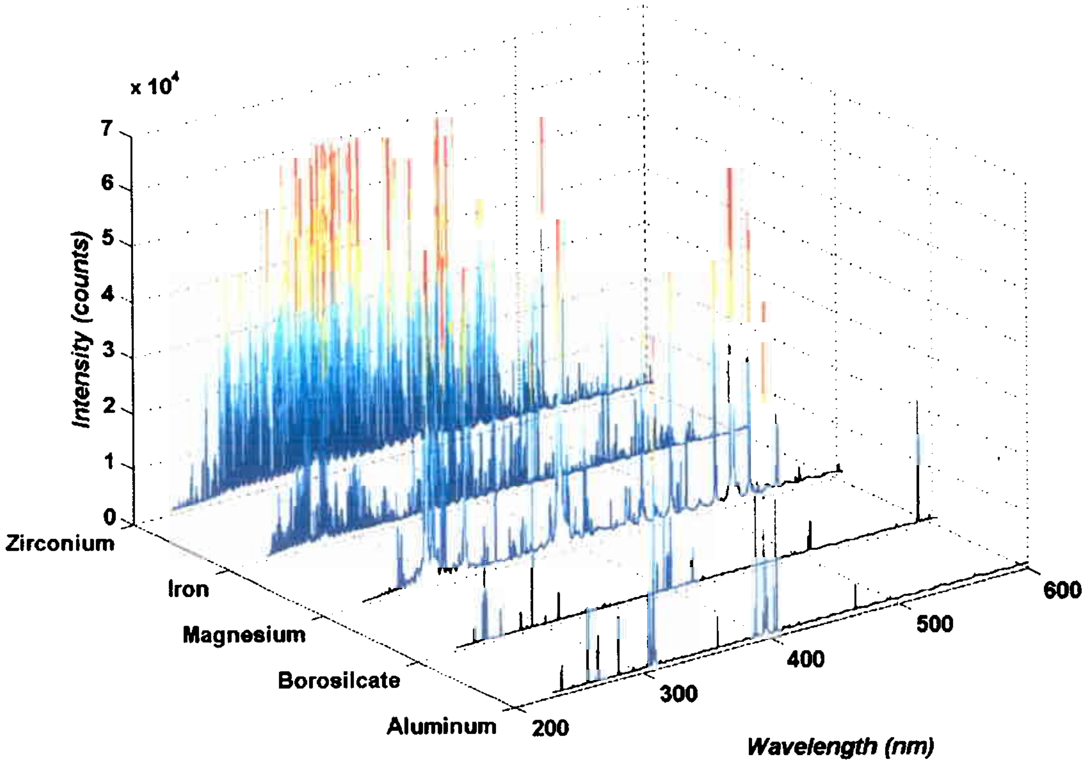


Figure 2: LIBS spectra

Having proven the ability to recognize and identify material, the project is now at the stage of building the database of IAEA interested material. Its further endeavouring to miniaturize the overall system, in order for an inspector to have the ability to hand carry the instrument. This ability will allow the IAEA inspector, with very little training and with no sample preparation to identify and quantify material even at large distances and in hostile environments. The LIBS technique offers a simple, fast multi-element detection capability which can reduce and possibly eliminate the need for swipe analysis. It could further be employed on-site to determine the enrichment level within a UF_6 flow or offsite within UF_6 cylinders. Because the CSSP is developing the technique in collaboration with other partners, the possibility of its uses seem endless as a tool within the IAEA inventory.

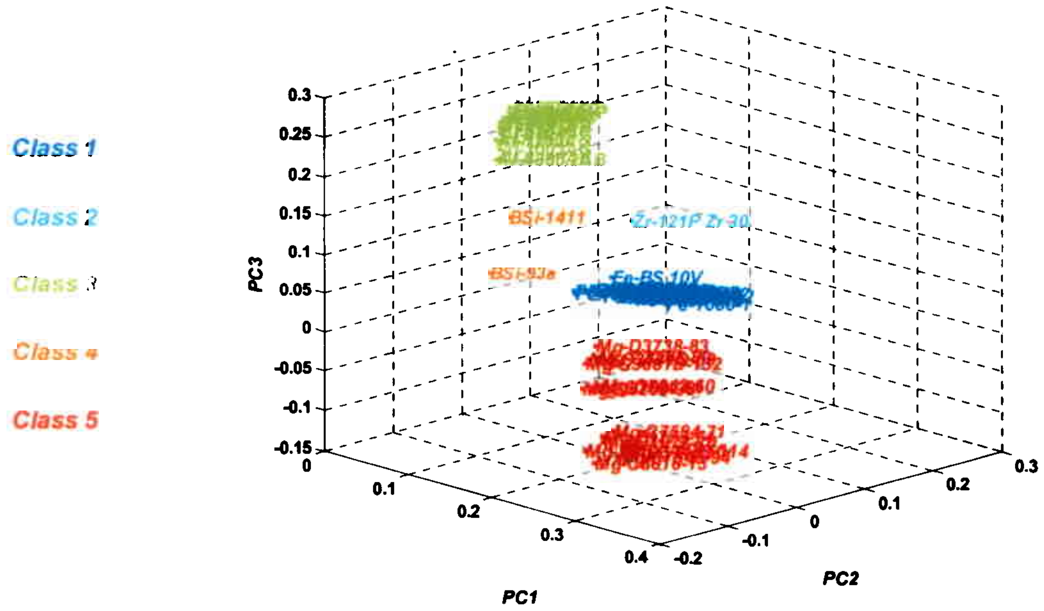


Figure 3: Clustering of the LIBS spectra obtained for the different certified reference materials using the first level Soft Independent Modeling of Class Analogy (SIMCA). (Class 1: Iron & Steel, Class 2: Zirconium, Class 3: Aluminium, Class 4: Borosilicate and Class 5: Magnesium)

Optically Stimulated Luminescence (OSL)

Like the LIBS, the OSL technology has an IAEA function. This is a method that uses optical stimulation to release stored energy within certain material that has been imparted by a nearby radioactive source. This energy is stored in the form of excited molecular states, some of which are metastable, and remain long after the source is removed. The release of this energy is induced by optical stimulation and the intensity of the resulting photon emission is proportional to the radiation dose absorbed by the material.

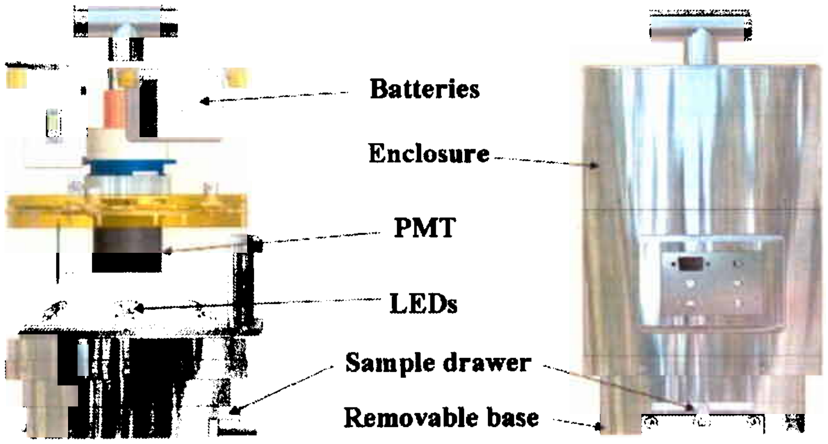


Figure 4: Laboratory Prototype OSL Reader Schematic

Figure 4 depicts a schematic of the laboratory prototype OSL reader. Clusters of blue-green Light Emitting Diodes (LEDs) provide stimulation light which is passed through a filter to eliminate short wavelengths and focused on the target. The luminescence emitted by the target is passed through U-

340 filters allowing transmission in the 300-400 nm range, and is detected by a photomultiplier tube. A sample drawer is provided for small samples of crushed material or the other option, is to remove the base for direct measurements of the suspect surfaces, such as concrete or ceramic tile.

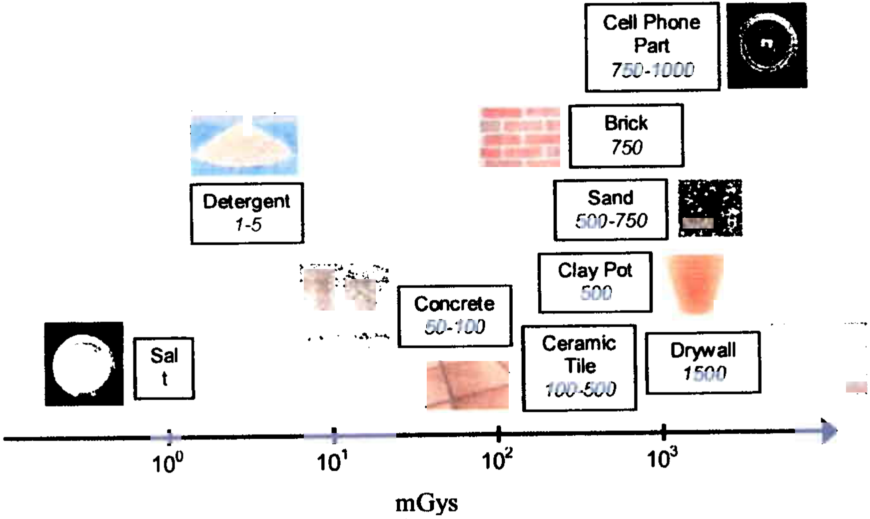


Figure 5: Sensitivity of OSL Emitters

This principle has been successfully applied for a forensic capability, where it clearly showed that many ubiquitous materials (such as concrete, dry wall, table salt, and even modern day semi-conductor components) exhibit strong OSL properties Figure 5. Figure 6 shows the actual results from three different materials. Not all of the materials tested to date emit an OSL signal. However, many of those that did emit an OSL signal are relevant to an investigation. Building material like brick, concrete, cement and sand do emit a detectable signal. This in turn allows police forces such as the Royal Canadian Mounted Police (RCMP) to positively identify the former location of a radioactive source. This same type of application can be used by the IAEA in its task to verify a State's declaration.

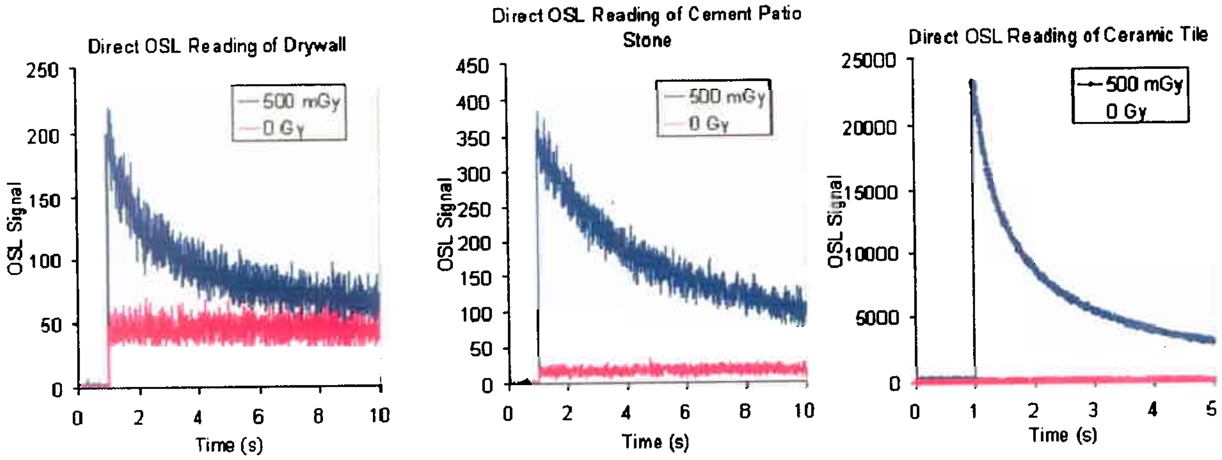


Figure 6: OSL Signals of 3 Forms of Building Material

A full scale portable prototype OSL has been designed, constructed and field-tested. Its operational utility was successfully demonstrated in a realistic scenario with participation by the RCMP, Figure 7.

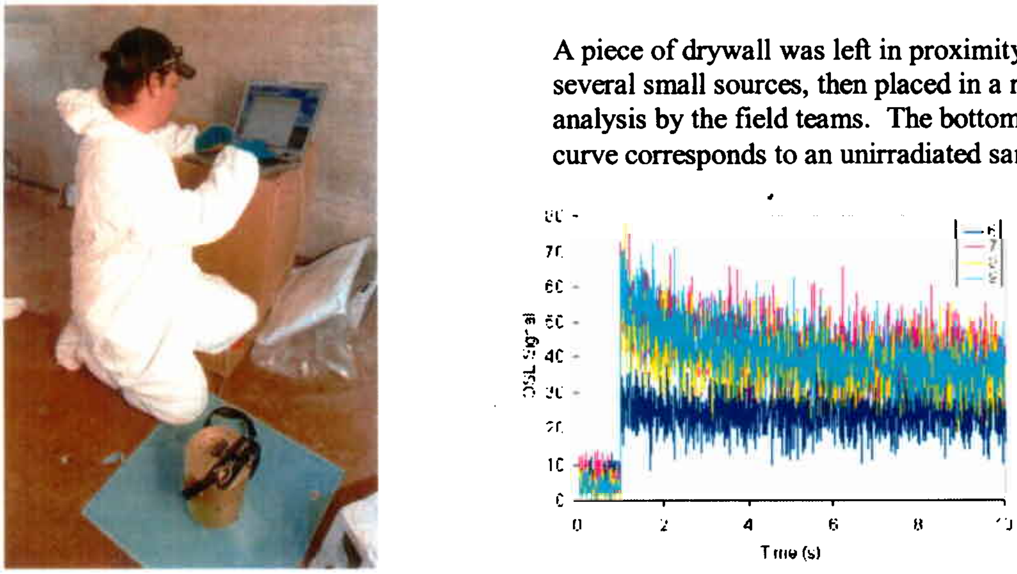

A piece of drywall was left in proximity to several small sources, then placed in a room for analysis by the field teams. The bottom blue curve corresponds to an unirradiated sample.

Figure 7: Field testing of the Portable Prototype OSL device

Following the success of the field tests, the project has progressed to the next stage, which will involve among other enhancements, miniaturizing the unit in order for it to be more practically useful. This phase will also involve the study and characterization of potential and previously identified OSL-emitting materials with the view in establishing a reference database. Specifically for the IAEA, the project is investigating samples of OSL emitting materials of international origin to determine if there is variability in the OSL responses. This information and instrument will give the IAEA the ability to use the device world-wide with the confidence to detect undeclared activities.

Fourier-Transform Infrared Radiometry (FTIR)

Studies have shown that materials such as U_3O_8, ThO_2, CsI, UO_2, UO_3, have distinctive absorption features in the thermal infrared region (8-14 microns) and have the potential of being detected by passive FTIR. The basic principle for detection requires that a reflectance contrast exists between the target and adjacent background area, and that there is a radiative (temperature) contrast between the target and surrounding environment. The spectral information of the target is used to detect the type of material.

Recently, the project has studied the reflectance spectra from various powder samples, Figure 8. Each studied material demonstrated a unique signature. Further investigations were performed to determine if these spectra could be identified from a standoff distance of 1m (representing a hand-held device) and 1 km (representing an airborne sensor). The simulated nadir direct and differential radiance at these distances for a surface reflectance based on laboratory measurements of UO_2 and UO_3 are shown in Figure 9, along with the Planck blackbody surface radiation as a reference of a non-reflecting surface. For the differential radiance, the charts

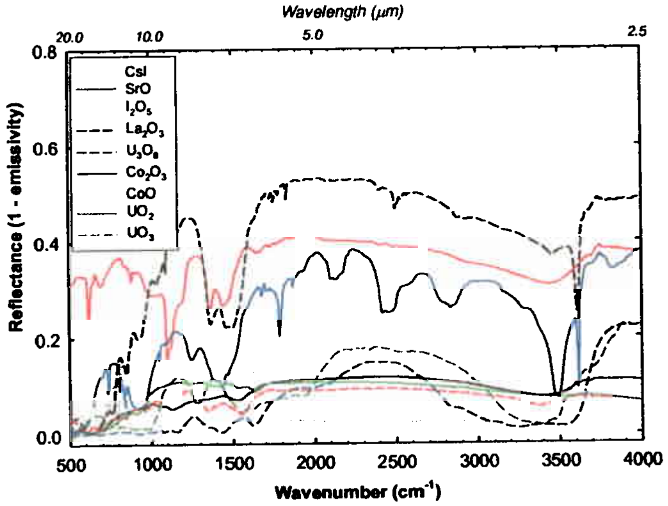


Figure 8: IR Absorption Signature of Radiological Products

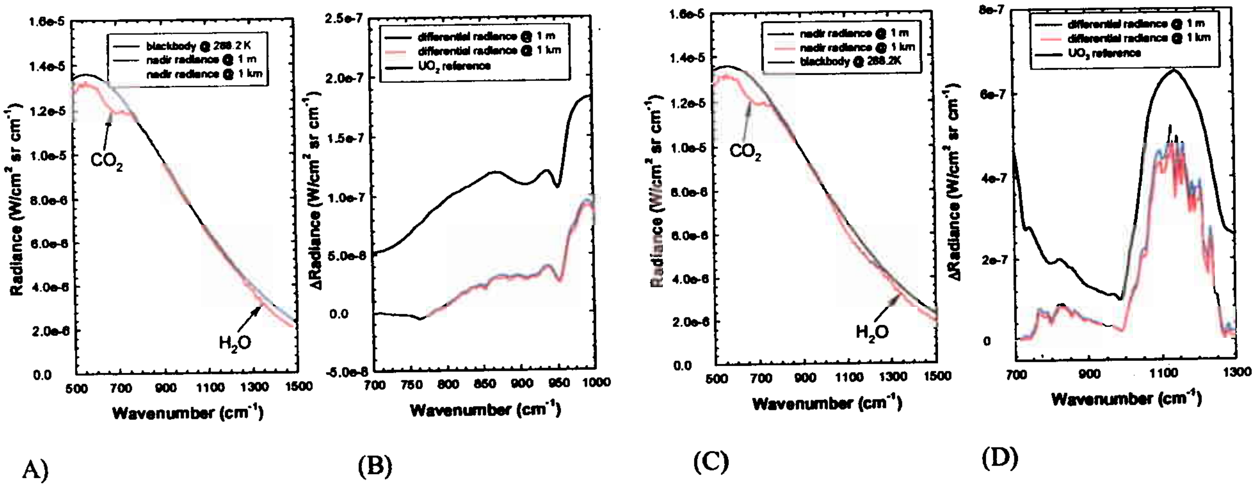


Figure 9: (A) Direct total nadir radiance simulated for two altitudes with a surface consisting of UO_2. (B) Differential radiance simulation showing the nadir radiance for a concrete surface subtracted from the nadir radiance for a surface of UO_2. (C) Direct total nadir radiance simulated for two altitudes with a surface consisting of UO_3. (D) Differential radiance simulation showing the nadir radiance for a concrete surface subtracted from the nadir radiance for a surface of UO_3.

depict the radiance simulated between the two identified materials and concrete. The direct simulated radiance for the materials was subtracted from a direct laboratory measured radiance emanating from a concrete surface. The solid black curve represents the reference differential spectra for the materials, using the spectra from the blackbodies. It is quite evident that the simulated capabilities of this method can distinguish the material from 1m and 1km.

A field test was performed to verify these findings. The results are depicted in Figure 10, confirming that FTIR can identify a material from a considerable distance.

The project is now determining if this method can detect and identify UF_6, confirm the simulated distance detection of UO_2, UO_3 and U_3O_8 and miniaturize the equipment as a lightweight person-portable instrument.

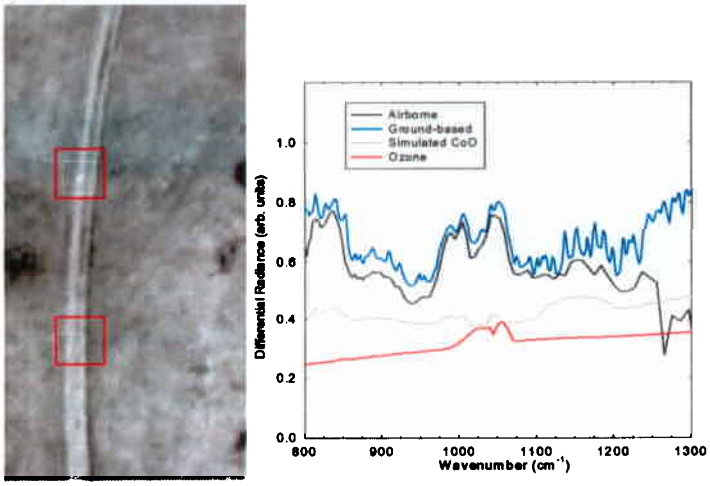


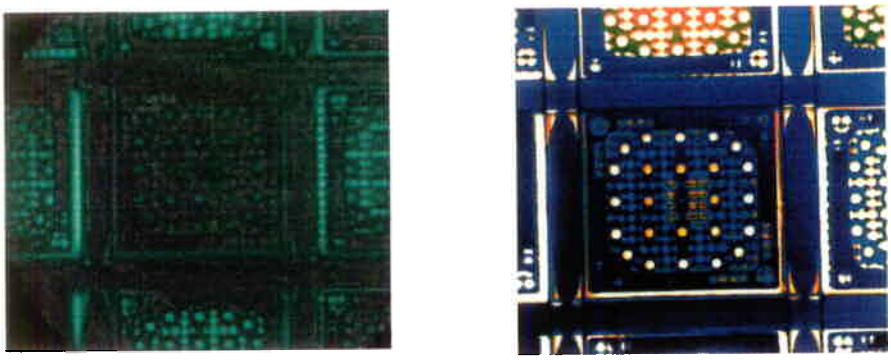
Figure 10: Airborne Detection of CoO at 1 km

Digital Cerenkov Viewing Device (DCVD) Ultra-Violet Zoom Lens

The CSSP sponsored DCVD technology, which has been authorized for use by the IAEA since 2005, has just been improved with the introduction of a UV zoom lens, Figure 11. This lens is the first known zoom lens that covers the UV-B spectrum (250 to 350 nm).

Figure 11: DCVD-e with UV Zoom Lens

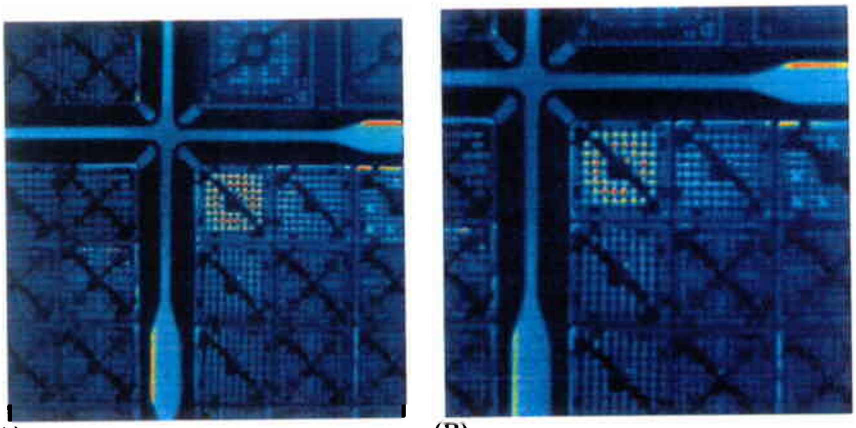
The DCVD displays an image of the UV light being emitted by the water surrounding Light Water Reactor spent fuel and non-spent fuel assemblies, Figure 12. To ease the operation of the instrument, the lens was developed to remove the redundant operation of interchanging of the 2 existing lenses (105 and 250 mm lenses), eliminate camera adjustments over the pond water, allow for easier location identification within the spent fuel pond, and ensure the IAEA has a viable lens for the foreseeable future. The present two lenses are no longer being manufactured.



(A) (B)

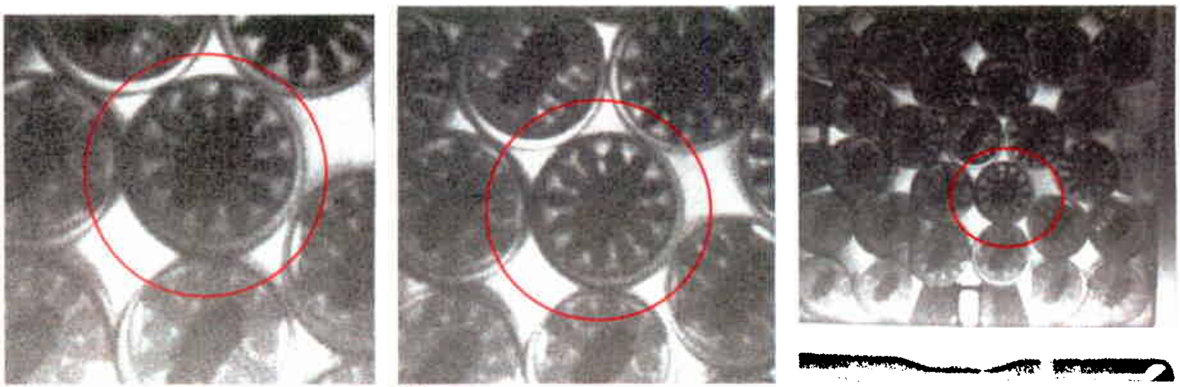
Figure 12: (A) A ICVD image depicting a PWR non-fuel assembly. (B) A DCVD image of the same assembly in false colour.

Operational-wise, the UV zoom lens performs like any other zoom lens. In this case, the focusing and zooming movements have been motorized. This aids in ease of operation and providing a better field of view. As can been seen in Figure 13, the 80mm field of view offers a better orientation by having more assemblies in the image. Figure 14 shows the light input and detail of the 200 mm lens image is clear than the 250 mm lens image. Even at the 80 mm focal length, the detail is quite clear. This light throughput is essential in the IAEA's ability to determine if the fuel assembly is either spent fuel or not. At a location 2 cm left of the aligned position, the zoom lens at the 200 mm focal length can identify the collimation where the 250 mm lens requires more distance away from alignment to detect this characteristic. This new feature to the DCVD enhances the IAEA's capabilities in detecting the absence and interchange of fuel rods.



(A) (B)

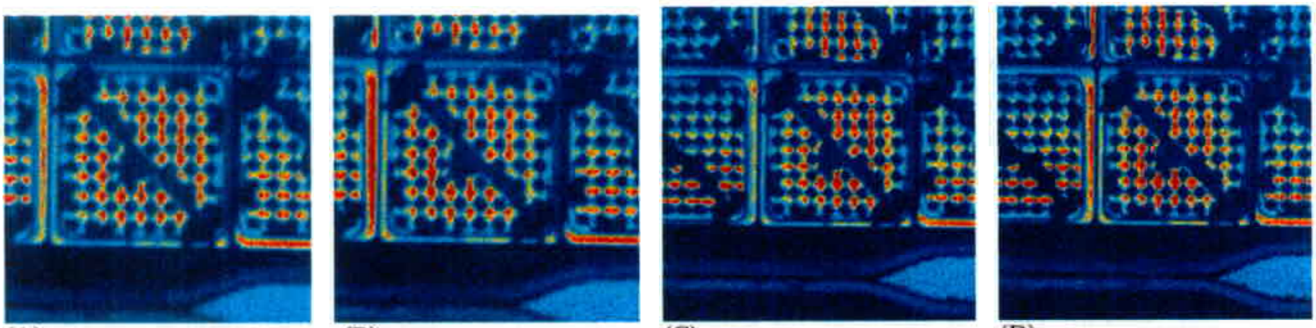
Figure 13: Field of views of a 40910 MWd/t U, 6 year cooled BWR spent fuel assembly using (A) 80 and (B) 105 mm focal lengths



[redacted]

(A) (B) (C)

Figure 14: Image details of a 1180 MWd/t U , 36 year cooled Ågesta spent fuel assembly using the (A) the 250 mm lens and the UV Zoom lens at (B) 200 mm and (C) 80 mm focal lengths.



(A) (B) (C) (D)

Figure 15: The collimation of a BWR fuel viewed using the 250 mm lens (A) aligned and (B) 2 cm left and using the UV Zoom lens at the 200 mm focal length (C) aligned and (D) 2 cm left.

Conclusion

As these four projects have demonstrated, emerging technologies can be sought to resolve IAEA challenges. Technologies can be new or novel. The keys are discovering them, adapting them to meet the IAEA's needs and delivering them in a timely manner. Each of these steps has its own challenges. Coordination between the IAEA, the CSSP its partnering organizations and industry when established early and maintained, minimizes these challenges. The CSSP continues to provide this coordination cornerstone enabling the IAEA to obtain state-of-the-art technology in order that they can safeguard nuclear material and equipment.

Acknowledgements

The author would like to acknowledge the many collaborators, without their efforts the specific work would be accomplished:

LIBS

M. Sabsabi & F.R. Doucet of the National Research Council Canada, Boucherville, Quebec, Canada; and J. Whichello of the International Atomic Energy Agency, Vienna, Austria.

OSL

T. Cousins, C.L. Larsson, & E. Inrig of Defence Research & Development Canada – Ottawa, Ottawa, Ontario, Canada; the funding by Chemical, Biological, Radiological and Nuclear Research and Technology Initiative (CRTI) program; D. Godfrey-Smith of Defence Research & Development Canada – CORA, Ottawa, Ontario, Canada; and J. Whichello of the International Atomic Energy Agency, Vienna, Austria.

FTIR

E. Puckrin of Defence Research & Development Canada – Valcartier, Valcartier, Quebec, Canada; and Q.S. Truong, Canadian Nuclear Safety Commission, Ottawa, Ontario, Canada.

DCVD UV Zoom Lens

J.D. Chen, A.F. Gerwing, D.A. Parcey, & B. Wilcox of Channel Systems Inc., Pinawa, Manitoba, Canada; K. Axell' J. Dahlberg & M. Larsson of the Swedish Nuclear Power Inspectorate, Stockholm, Sweden; B. Lindberg of Lens-Tech AB, Skellefteå, Sweden; F. Vinnå of Mindcell, Kista, Sweden; and R. Carchon of the International Atomic Energy Agency, Vienna, Austria.

References

1. M. Sabsabi, *LIBS: a New Tool for Real-Time Analysis of Materials* presentation at the Technical Meeting on Application of Laser Spectrometry Techniques in IAEA Safeguards, Vienna, Austria, August-September 2006.
2. F. Doucet & M. Sabsabi, *Evaluation of LIBS for inspection of materials in Safeguard applications for nuclear activities*, NRC – Boucherville, PQ, Canada, March 2007
3. C.L. Larsson, et al, *Optically Stimulated Luminescence in Forensics*, 8th International Conference on Applications of Nuclear Techniques, September 2004.
4. E. Inrig & C.L. Larsson, *Forensic Applications of Optically Stimulated Luminescence,* International Technical Working Group Nuclear Forensic Laboratories Meeting, Delft, Holland, Netherlands, June 2007
5. E. Puckrin, et al, *Standoff Detection and Identification of Nuclear Materials by Passive FTIR Radiometry*, International Safeguards Workshop , Advanced Sensors for Safeguards, Santa Fe, NM, United States, April 2007
6. E. Puckrin, et al, *Recent Advances in the Remote Sensing of Radiological Materials by Passive FTIR Radiometry,* DRDC-Valcartier, Valcartier, PQ, Canada, March 2006
7. J.D.Chen, et al, *DCVD Enhancements: UV Zoom Lens Development*, CSI, Pinawa, MB, Canada, November 2007