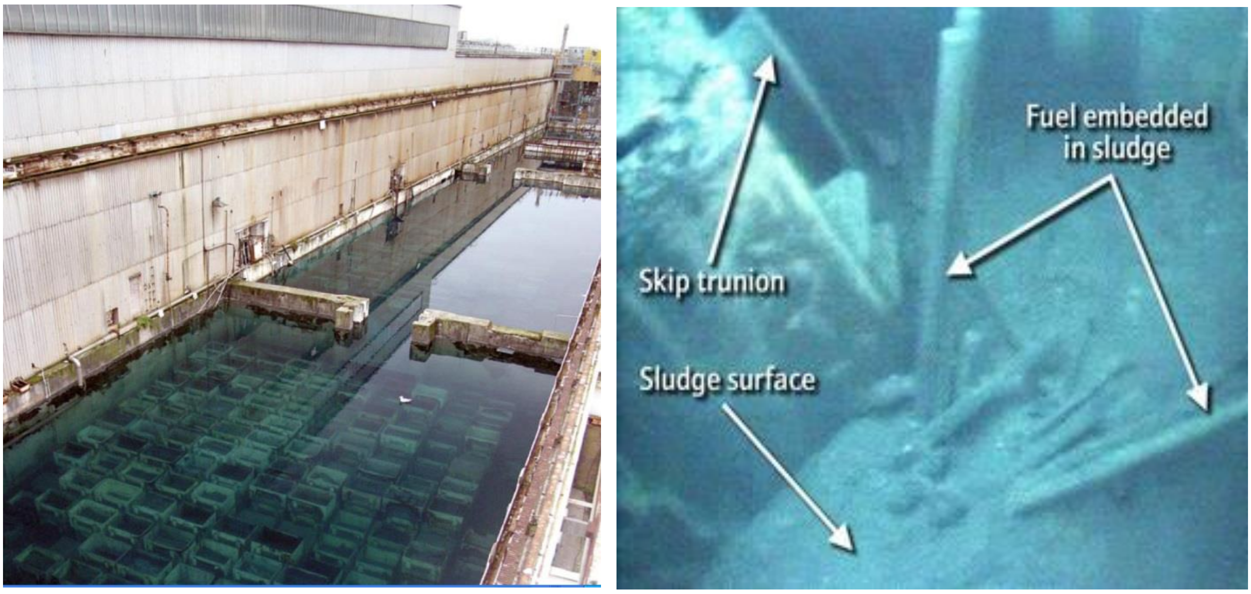
A technical demonstration of a submersible FO-LIBS probe developed by APL

This was the first of three inactive technical demonstrations to show the applicability of LIBS technology in selected application areas of interest to nuclear decommissioning. The aim of this particular demonstration was to show the ability of APL's *LIBSProbe* technology to quickly and reliably identify various solid materials submerged in water (or sludge) up to a depth of several metres. The potential application area is that of the in-situ characterisation and identification of materials within redundant spent-fuel storage ponds. The following provides a brief overview of this application area.

Many of the early-design spent fuel cooling ponds were open to the atmosphere although the more modern ponds utilise a fully enclosed structure to minimise the deposition of airborne contaminants such as salt spray (in coastal sites) or bird droppings. Open ponds are exposed to sunlight and hence suffer greatly from algal growth which can reduce underwater visibility to such a degree that it becomes virtually impossible to visually identify submerged items.



Typical early-design spent fuel cooling pond containing corroded fuel and waste materials

Modern spent fuel cooling pond

Many of the early cooling ponds are now redundant and so are in various stages of the decommissioning process. Some of these ponds were used as temporary storage sites for a wide range of radioactive waste and so now contain a largely unknown inventory of miscellaneous items of equipment and materials

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including spent fuel. In addition to having poor visibility due to the presence of algae and other organic material, the water within these older facilities is often heavily contaminated with radionuclides, in dissolved or suspended form, originating from corroded spent fuel assemblies. During the clean-out phase of the decommissioning work, it is necessary to characterise and identify components and materials stored in the pond prior to their removal. One way of achieving this is to obtain physical samples of each component / material so that a laboratory analysis may be carried out. Removal of material from the water can expose personnel to nuclear radiation and may also increase the risk of contamination spread. Furthermore, physical sampling followed by laboratory analysis is a very time-consuming and hence costly process. Characterisation of the component / material whilst it is submerged (i.e. *in-situ* characterisation) could offer significant advantages in terms of safety, speed and overall cost reductions.

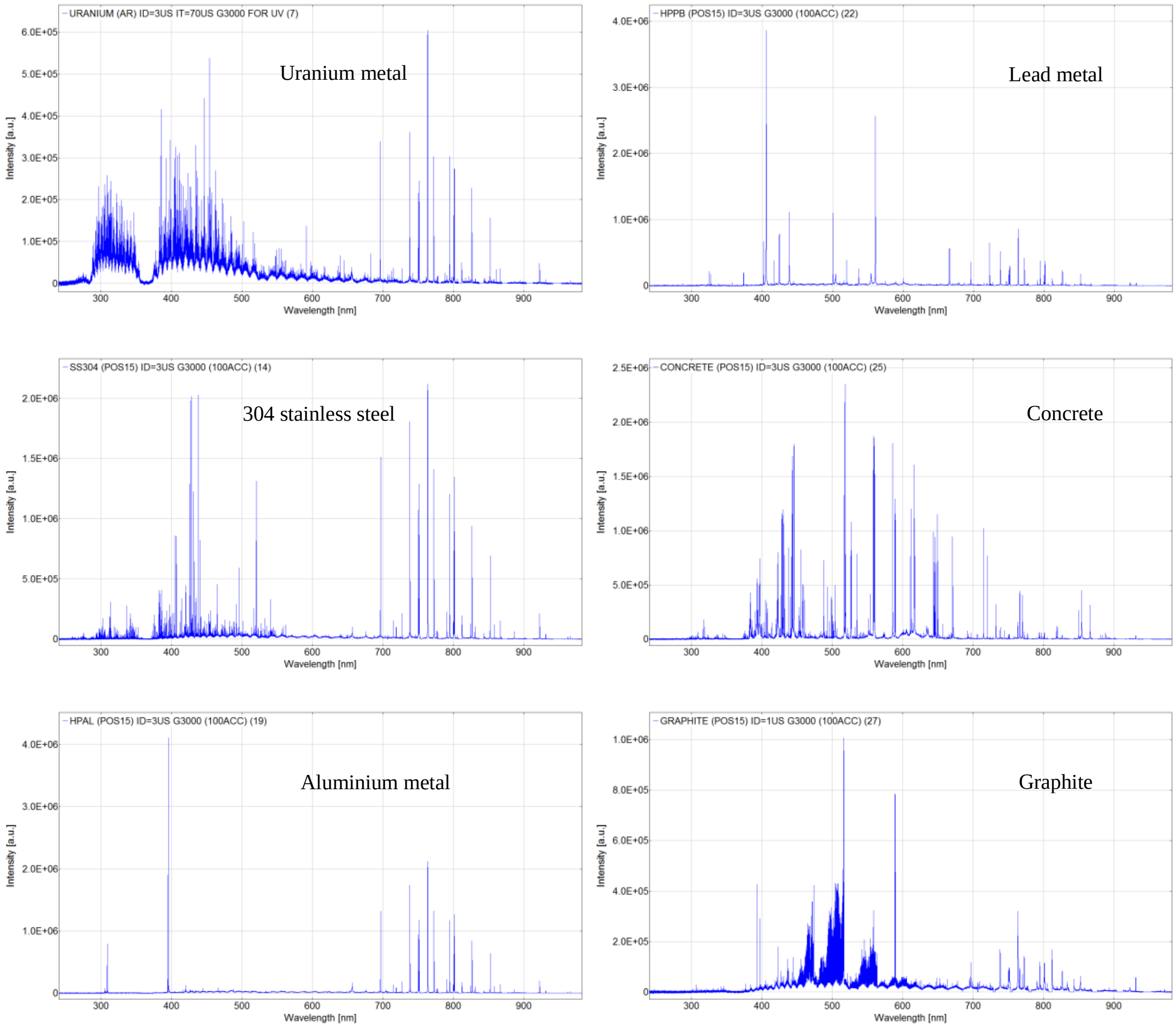
A special version of APL's LIBS*Probe* FO-LIBS instrument which incorporates a submersible remote probe is able to identify the elemental composition of materials submerged in water at any depth up to ~30 metres. The probe operates by ejecting a small amount of gas (air or preferably argon) through the nozzle aperture of the probe. When the probe is in contact with the component under investigation, the water is displaced from the optical path of the laser beam by the gas flow, thus allowing a LIBS analysis of the material to be conducted in a gas medium rather than a liquid medium.

Only a "loose" seal between the probe and the component is required – the probe does not have to be normal to the surface of the material and can even tolerate a gap of up to approximately 2 mm. Remote manipulation of the probe is therefore greatly simplified since precise positioning is not required. The small stream of gas escaping from the nozzle of the probe prevents the ingress of water even when the probe is not in contact with the surface of a material.

APL's submersible FO-LIBS probe being used to analyse objects submerged in water

Data analysis

A variety of materials may be quickly and reliably identified using this instrument including uranium, stainless steel, zircalloy, graphite, aluminium, lead and many others. The following raw spectral data obtained using the submersible FO-LIBS instrument illustrate how it is able to discriminate various materials. Analysis is extremely quick and in many cases can be performed in a matter of seconds. A technical demonstration of this underwater detection, made to representatives from the UK nuclear industry, is described later in this section of the report.



Examples of spectra recorded using the submersible LIBS probe

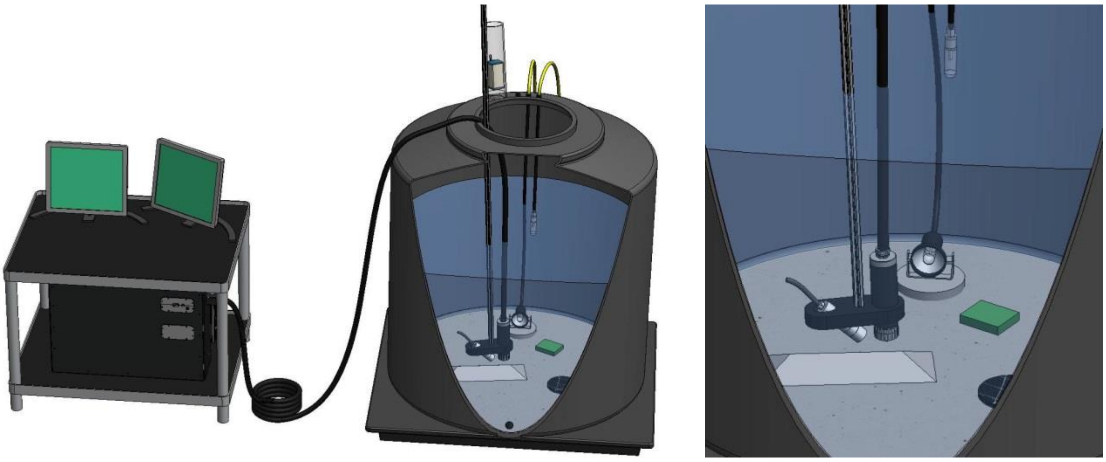
The submersible probe also has other, non-nuclear applications. For example APL have supplied a system to the University of Malaga, Spain, for use in the in-situ analysis of marine archaeological artefacts. This system has been used successfully at depths up to 30 metres in the Mediterranean Sea.

Loading the FO-LIBS instrument on board ship for deployment in the Mediterranean Sea (images courtesy of University of Malaga)

Deployment of the submersible FO-LIBS probe at depths of up to 30 metres (images courtesy of University of Malaga)

Technical demonstration

The demonstration rig is illustrated schematically in the following diagrams.



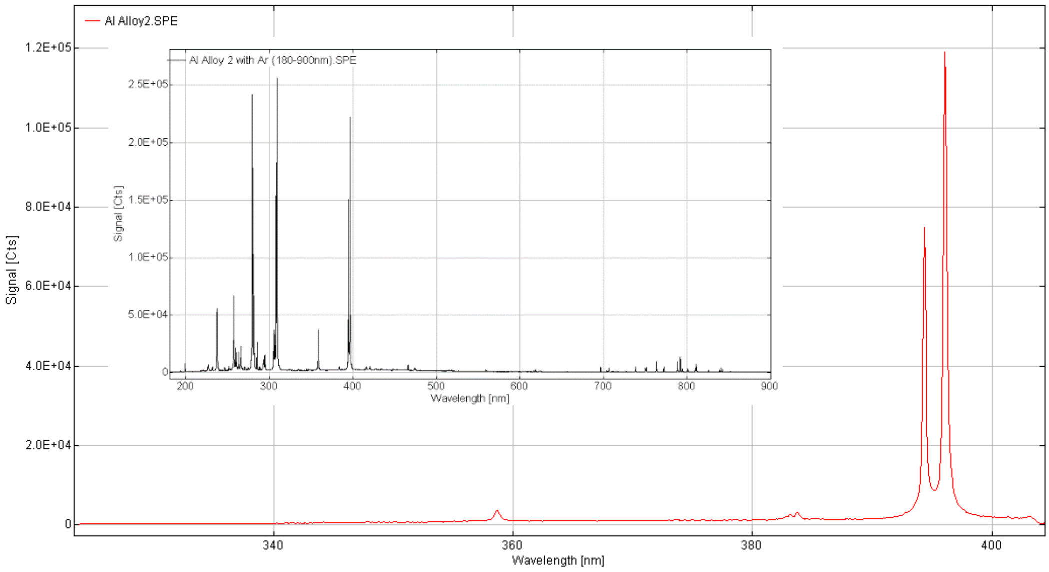
Submersible FO-LIBS probe and large water tank, 1200 litres volume, approx. 1.3 metres height

Submersible FO-LIBS probe and water-filled transparent polycarbonate tube, 350 mm diameter and 2 metres height

The equipment used consisted of a submersible gas-purge FO-LIBS probe connected to the main LIBS instrument unit via a 10 metre length of flexible umbilical. The purge gas used during this demonstration was argon at a pressure of approx. 5 psi. To facilitate deployment in the water tank, the probe was attached to a metal rod of length ~1.5 metres and was equipped with two submersible video cameras – one near the probe to provide a close-up view of the probe aperture, and another positioned at the mid-point of the metal rod to provide a general view of the submersible probe. The demonstration rig consisted of i) a large water tank of approx. 1200 litres volume, ii) a water filled transparent tube of diameter 350 mm and height 2 metres, and two builders buckets, one containing a mixture of gravel and water and the other containing a mixture of sand and water. The large water tank contained various items representing "unknown" materials / items of pond inventory and the inside of the tank illuminated using two submersible flood lights. The items using during this demonstration are as follows:

Concrete	Lead	Copper	Zircaloy	316 Stainless Steel
Graphite	Vit Glass	Phosphor Bronze	Aluminium Alloy	Magnesium

Previously recorded LIBS spectra of the various items were printed on paper and displayed on the wall next to the large water tank. These spectra were recorded using an Acton Research triple-grating spectrometer (model SP500) fitted with a Princeton Instruments IPDA detector. The spectra are relatively "narrow band" (ie. approx 80 nm) but contain sufficient spectral information to easily distinguish the materials being analysed during this demonstration. In a real-world application, it would be desirable to use a "broad-band" spectrometer so as to obtain a better spectral fingerprint of each material of interest which would increase the level of confidence of correct identification of an unknown material. The narrow-band spectra used during this demonstration are as follows ("broad-band" spectra shown as insets):



Aluminium Alloy

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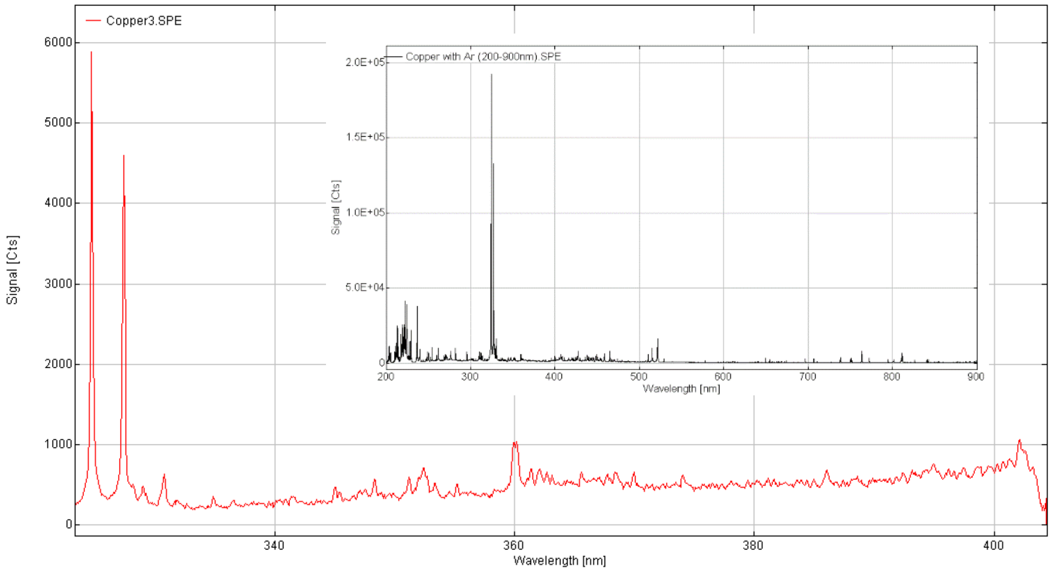
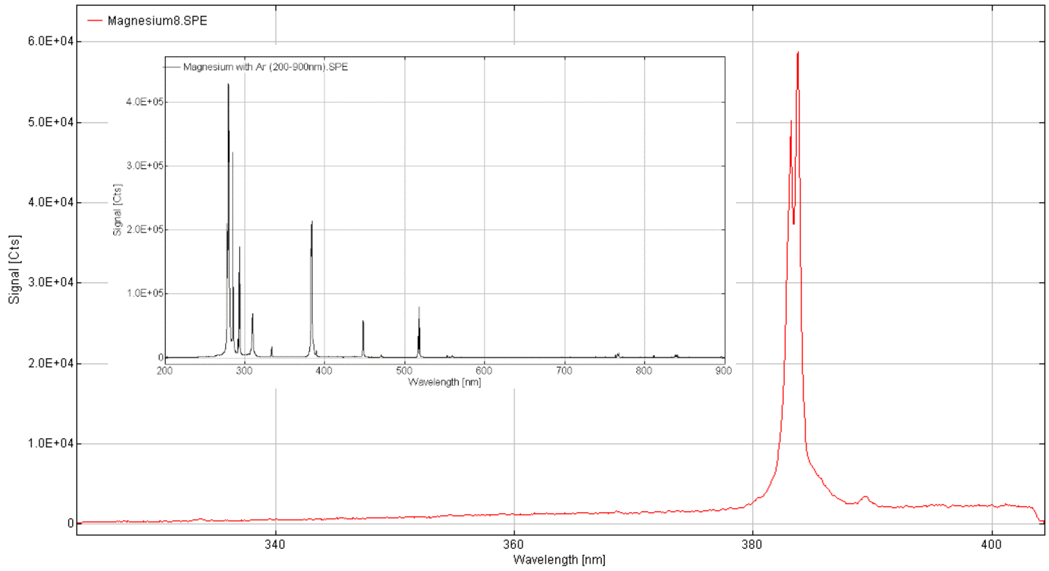
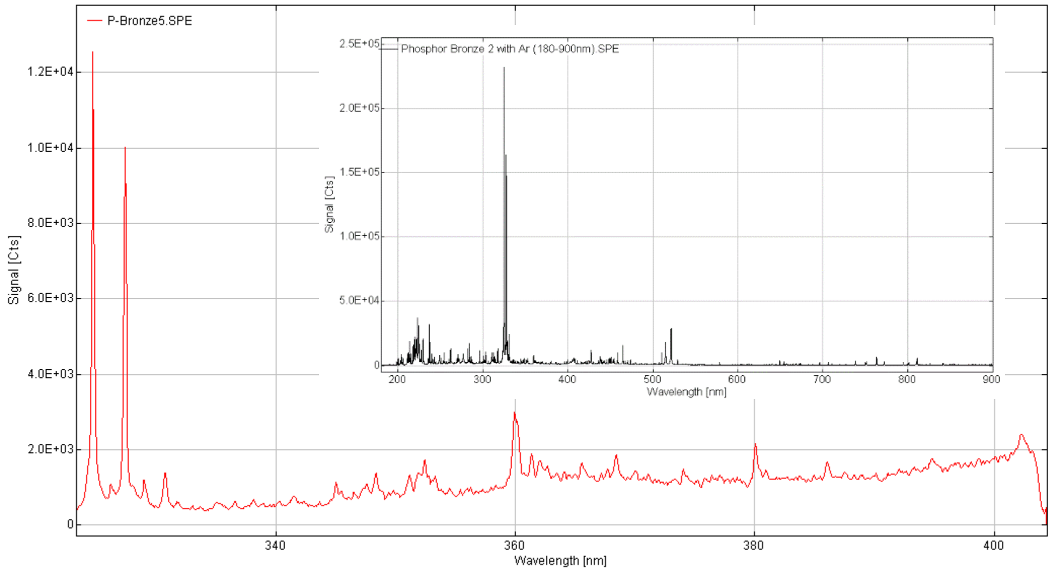


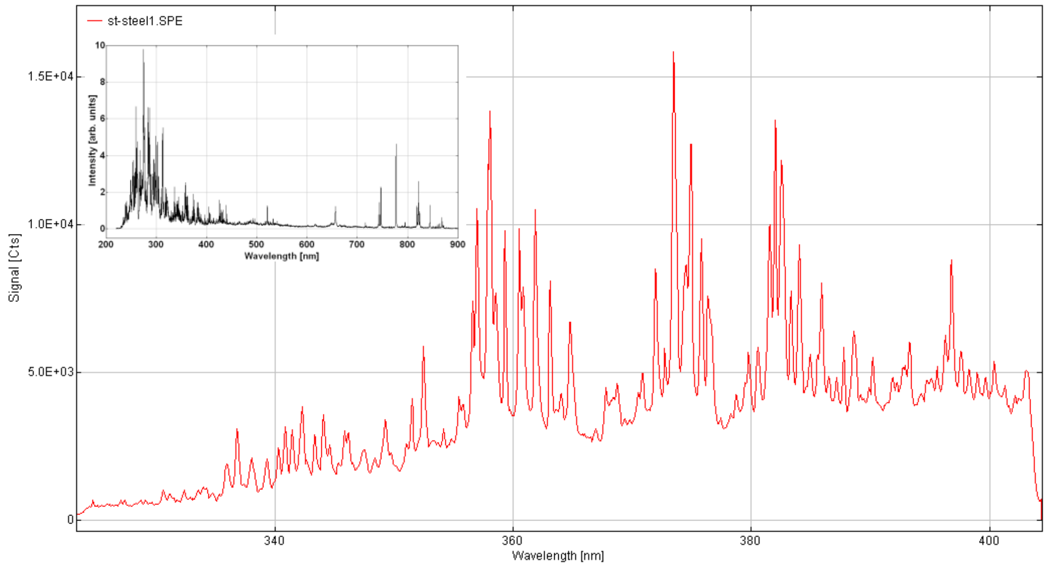
Copper



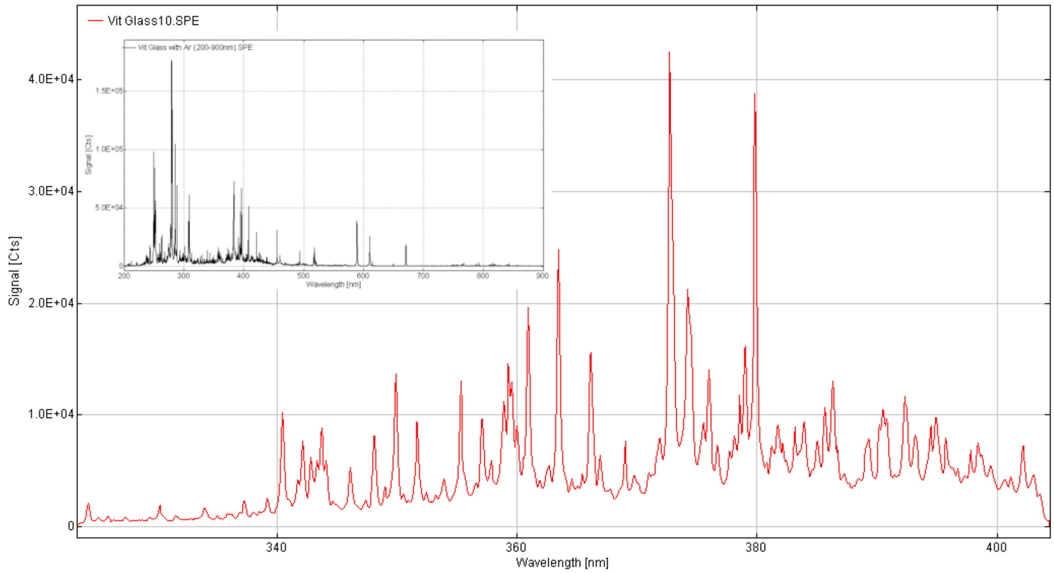
Magnesium



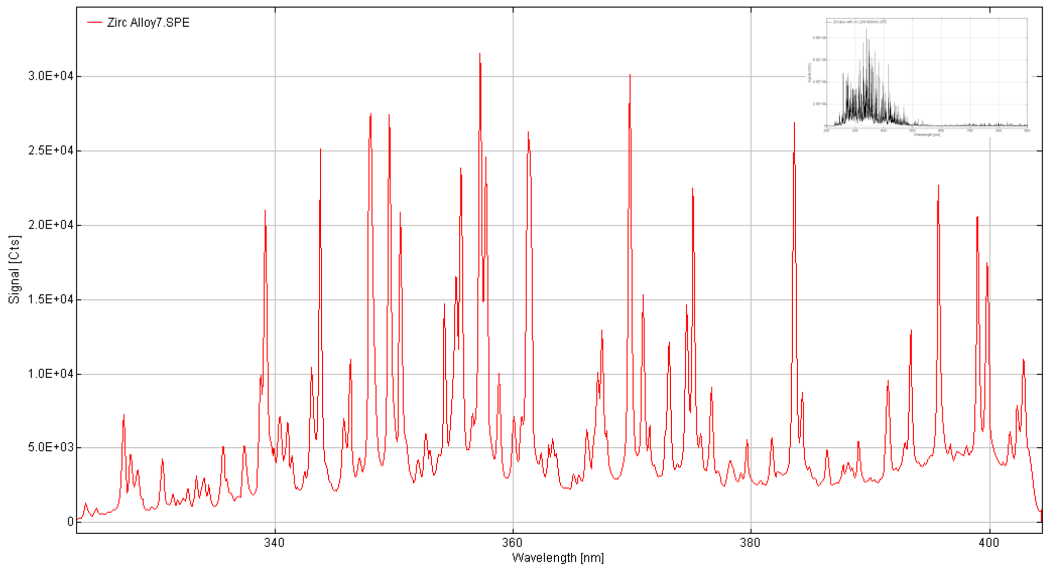
Phosphor Bronze



316 Stainless Steel



Vit Glass



Zircaloy

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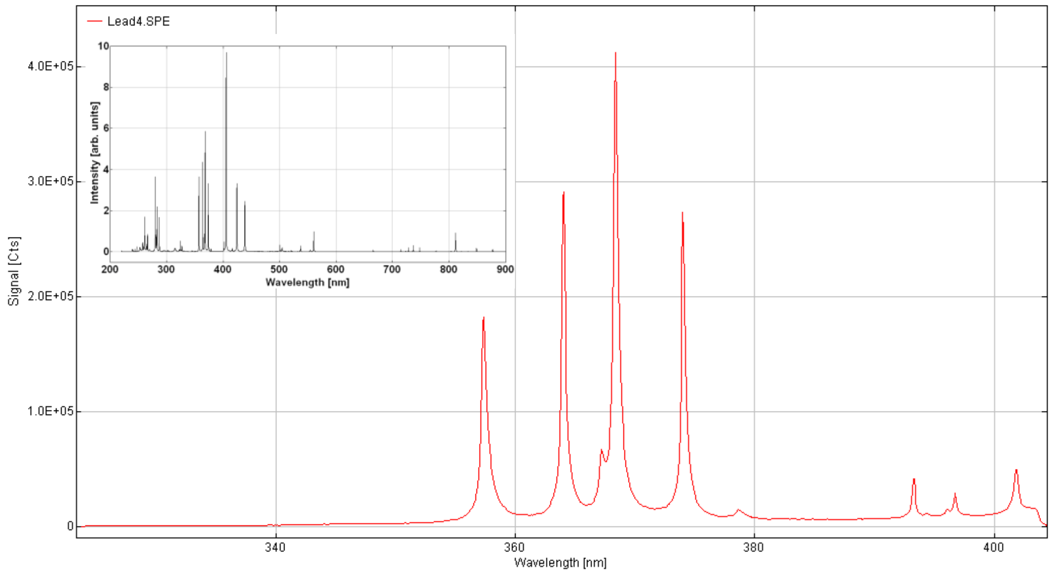
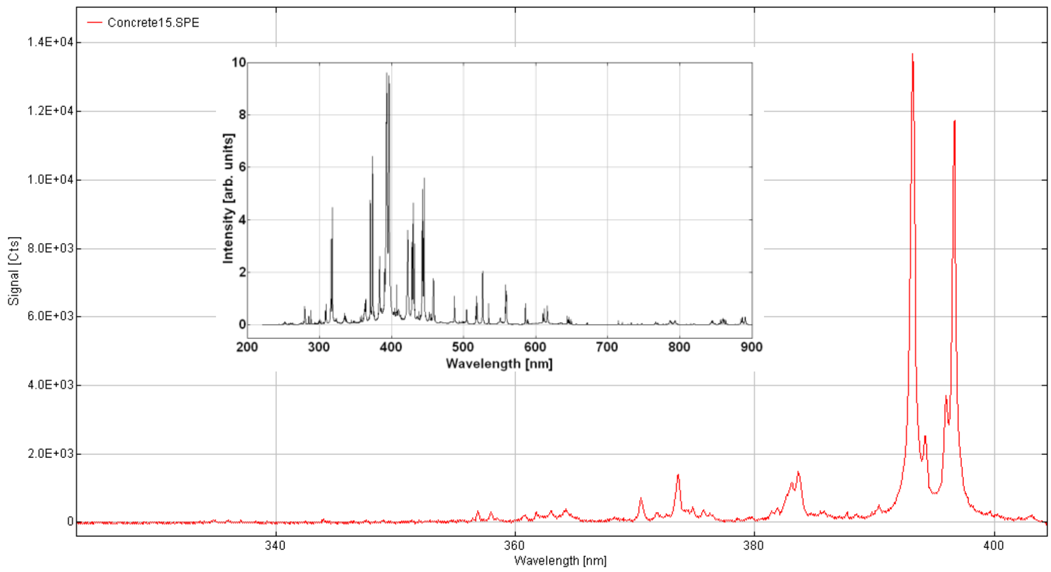


Lead

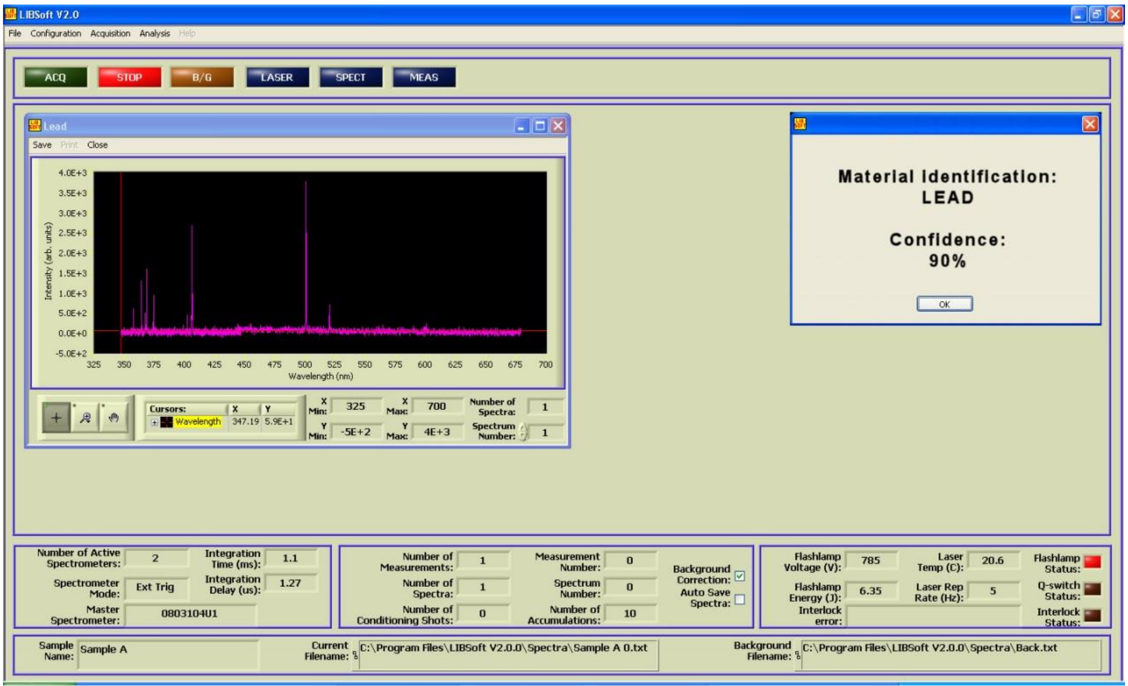


Concrete

The video images from the two submersible video cameras were displayed on two monitors while the recorded LIBS spectra were displayed on a third monitor. During the demonstration, the attendees were invited to compare, for each submerged item analysed, the displayed LIBS spectrum with the previously recorded LIBS spectra posted to the wall. Once the FO-LIBS probe was placed in contact with an item, the LIBS spectra were recorded repeatedly with a refresh rate of 0.5 Hz (ie. a new spectrum displayed every 0.5 second). In all cases, correct identification of the submerged item was made within seconds of placing the LIBS probe on the item. This was repeated using sample items placed in the builders buckets (ie. gravel/water and sand/water to a depth of approx. 300 mm) to demonstrate that the submersible FO-LIBS probe is able to operate within silty / zero visibility water. The FO-LIBS probe was also able to identify items buried under the sand by manually pushing the probe into the sand and manipulating the probe until it made contact with a buried item.

Identifying materials submerged in clean and turbid water using a submersible FO-LIBS probe

APL has developed software for automatic identification of materials from the raw spectral data produced by the submersible FO-LIBS probe instrument. The software has the following features i) control of the laser ii) control of the spectrometers, iii) data acquisition and storage, and iv) real-time data processing and user-friendly display of the material identification results. The following image illustrates the graphical user interface.



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