Institution: Swansea University
Unit of Assessment: 9 - Physics
Title of case study: Applications of laser spectroscopy techniques to the nuclear, defence and aerospace industries
1. Summary of the impact

A range of techniques based on laser physics and developed since 1993 by the group of Prof **Telle** in our **analytical laser spectroscopy unit (ALSU)** has led to:

- Founding a spin-off company, **Applied Photonics** which produces remote-sensing products employing laser spectroscopy to detect the chemical composition of unknown samples aimed at the **military and nuclear energy industry**. This technology has allowed multi-million pound savings on the operational costs of nuclear plants due to their functionality in normally inaccessible radioactive environments thus avoiding the need for a power station shutdown.
- Establishing a laboratory in the **Atomic Weapons Establishment** (AWE) dedicated to the stewardship of UK's nuclear weapons stockpile and chemical explosives by detecting isotopic abundances in uranium samples and analysing the composition of munitions deteriorating in desert environments;
- Assisting the design and development of a new product line of **Spectrum Technologies**, a market-leading company which removes specialised enamel insulation from conductors used in the aerospace industry.

2. Underpinning research

Since the mid-1990s, **Telle** (at Swansea from 1984) and his team at the ALSU have developed laser techniques for detecting and identifying chemical species at trace concentrations in a wide variety of conditions by analysing their absorption spectra. Such techniques include:

Laser-induced breakdown spectroscopy (LIBS) [R2-R6]

In LIBS, a high-power laser is shot at a sample, generating a micro-plasma whose spectrum is analysed to yield information about the sample's chemical composition. Telle's group began developing LIBS in 1995, with an emphasis on achieving remote implementations via a single optical fibre and the ability to probe samples in underwater environments. Telle and colleagues addressed and solved these issues in [R2-R6, G2, G3]. This research has also been applied to strip insulators from critical safety components in the aerospace industry by laser-induced plasma ablation.

Resonance Ionisation Mass Spectrometry (RIMS) [R1]

RIMS was developed at the ALSU under Telle's leadership [R1], during the period 1990-1998, and led to a DTI/SERC programme and the involvement of industrial partners [G1]. In RIMS, a small plume of the sample is created by either a high-power laser or ion-beam bombardment; a laser is then tuned to a resonant transition of the particular isotope being analysed; a further photon ionises the atoms in the plume which are then analysed in a mass spectrometer. RIMS builds on and complements Secondary Ion Mass Spectrometry, which is a widely used analytical technique. The advantage compared to other analysis techniques is that only the element of interest is ionised; this facilitates the accurate measurement of isotope abundances which may be otherwise difficult to detect due to the presence of interference by other constituents. Telle's work illustrated the effectiveness of RIMS in isotope measurements in the decay chain of uranium [R1].

Tunable Diode Laser Spectroscopy (TDLAS) [C1]

Telle also developed table-top TDLAS systems to analyse trace quantities of gases in 2002. TDLAS was quickly exploited by AWE who commissioned further research [G4] which

demonstrated its ability to analyse gases emitted from chemical explosives as they deteriotated. Much of this work is confidential and the contract prohibits publication, but it has led to reports [C1].

3. References to the research

Publications (R1, R2 and R5 are the publications which best represent the quality of the research. Swansea authors are in bold):

[R1] **Telle, HH**; **Telyatnikov, AL**; McNaghten, ED; Brown, RA; McCormick, A; "Isotope ratio measurements in lead using 3-photon one-color resonance ionization", *Rapid Communications in Mass Spectrometry* **7**, 524-527 (1993). doi:10.1002/rcm.1290070625. [Impact factor 2.8]

[R2] **Davies, CM**; **Telle, HH**; Montgomery, DJ; Corbett, RE; "Quantitative analysis using remote laser-induced breakdown spectroscopy (LIBS)", *Spectrochim. Acta B* **50**, 1059-1075 (1995). doi:10.1016/0584-8547(95)01314-5. [Impact factor 2.7]

[R3] **Davies, CM; Telle, HH; Williams, AW**; "Remote in situ analytical spectroscopy and its applications in the nuclear industry", *Fresenius J. Anal. Chem*. **355**, 895-899 (1996). doi:10.1007/s0021663550895. [Impact factor 3.8] Cited by 36 in Google Scholar

[R4] **Samek, O**; **Beddows, DCS**; Kaiser, J; Kukhlevsky, SV; Liska, M; **Telle, HH**; Young, J; "Application of laser-induced breakdown spectroscopy to in situ analysis of liquid samples", *Opt. Eng*. **39**, 2248-2262 (2000). doi:10.1117/1.1304855. [Impact factor 1.7] Cited by 130 in Google Scholar

[R5] **Beddows, DCS; Samek**, **O**; Liska, M; **Telle, HH**; "Single-pulse laser-induced breakdown spectroscopy of samples submerged in water using a single-fibre light delivery system", *Spectrochim. Acta B* **57**, 1461-1471 (2002). doi:10.1016/S0584-8547(02)00083-6. [Impact factor 2.7] Cited by 44 in Google Scholar

[R6] **Beddows, DCS; Telle, HH**; "Prospects of real-time single-particle biological aerosol analysis: A comparison between laser-induced breakdown spectroscopy and aerosol time-of-flight mass spectrometry", *Spectrochim. Acta B* **60**, 1040-1050 (2005). doi:10.1016/j.sab.2005.05.018. [Impact factor 2.7]

Key industrial sponsorship / funding:

Much of this research has been funded by industrial partners and customers, including BNFL plc; AWE Aldermaston; Renishaw plc (Raman Spectroscopy Division); Nuclear Electric (now Magnox Ltd, part of EDF Energy); and British Steel (now Tata Steel Ltd). Grants include:

[G1] **Telle, HH** (PI) DTI/SERC Link grant, GR/F41136 (1989-94) £167k

[G2] **Telle, HH** (PI) "Remote in-situ assaying of materials using laser-analytical spectroscopy", EPSRC ROPA grant GR/K 34665 (in cooperation with BNFL plc, Sellafield) (1994-1996) £108k

[G3] **Telle, HH** (PI) "Development programme for in situ and remote LIBS", BNFL plc, Sellafield (1995-2001) £120k

[G4] **Telle, HH** (PI) "Application of tunable diode laser spectroscopy to trace gas analysis" and "Development of bench-top TDLAS for NO_2 detection at trace levels", AWE (MoD), contracts OCE0792 and CPO0638 (1998-2005) £110k

4. Details of the impact

The research by Telle and co-workers at the **ALSU** on laser technologies has had substantial impacts on industry. The table below summarises the nature, reach and significance of this impact on three companies.

Company	Impact	Reach	Significance
Applied Photonics	Founding of spin-off company and providing its core business	UK & US nuclear industry	Maintenance of nuclear power stations – £multi-million savings
		US military	Remote assaying device
Atomic Weapons Establishment	Specialist laboratory established	Defence of the Realm	Stewardship of UK nuclear stockpile and chemical explosives
Spectrum Technologies	New product line to strip aerospace conductor insulation	Global sales to the aerospace industry	Maintenance of company's leading market position

A spin-off company using LIBS for remote analysis

LIBS was used by the **ALSU** from 1994 as an analytic tool for the nuclear industry, allowing *in situ*, remote analysis of the structural integrity of the steel containers of nuclear-fuel cells whilst in the reactor environment. **Based on the research in [R3]**, a £100k system [G2, G3] was designed by **ALSU** to allow uninterrupted operation of power stations during assaying, thus avoiding the need for a reactor shutdown for significant periods of time. This saved £4m per day, based on the power stations' wattage output and the cost of commercial electricity in kWhr.

In order to provide LIBS analytic services to the nuclear industry on a larger scale, a spin-off company, **Applied Photonics Ltd**, was established in 1998 by Dr A.I. Whitehouse, a former PhD student at **ALSU**. The company operated in collaboration with Telle and his team and has **utilised the research described in [R2-R6]**. Applied Photonics has now developed into a major provider of LIBS services and manufacturer of LIBS equipment. It is based in North Yorkshire and currently employs around 20 staff (in the UK and the USA) – recently it entered into a strategic partnership with Energy Research Company (ERCo), Staten Island, NY.

Applied Photonics has an extensive product portfolio ranging from hand-held devices that allow easy characterisation of samples to bespoke, submersible LIBS probe systems that perform *in situ* analysis of materials within **spent-fuel storage ponds for the UK nuclear industry**. The economic impact of this LIBS technology is measured by the multi-million pound savings enabled by avoiding the shutdown of nuclear power stations, thanks to the use of Applied Photonics' remote, robotic assaying devices. From [C2]:

> *"…I write to acknowledge the impact that your research has had in some of the developments in Applied Photonics over the past years. Your research work and your collaboration with us in the area of laser-induced breakdown spectroscopy (LIBS) have been essential to the development of remote LIBS capabilities in material-assaying."*

In 2009, Applied Photonics also delivered a stand-off LIBS system to the US Army that can determine the chemical composition of samples over distances in excess of 100 m, by means of a high-power laser and telescopic spectrometer. Around two-thirds of Applied Photonics' current business is now with the **US military and nuclear industry**, and while the system developed in 2009 is in the public domain [C2], more recent advances are subject to confidentiality.

Analysis of nuclear and chemical explosive material for the Atomic Weapons Establishment

The **AWE** entered a research collaboration with the **ALSU** in 1993 to determine the isotopic abundances in uranium samples by performing RIMS on the final products in the decay chain (lead) **[R1]**. As a proof-of-concept, uranium specimens were analysed in-house by **ALSU** [C3]. The **AWE** also enlisted Telle's TDLAS expertise in analysing the composition of its chemical explosives, which had an unacceptably high failure rate during the first Gulf War due to their exposure to heat [G4, C1]. Recognising the efficacy of these techniques, in 2003 **AWE** founded a laboratory in its Materials Science Research Division to utilise this technology – from [C3]:

"your work in the areas of LIBS and TDLAS has been essential in our laboratory's expansion"

Since 2007, the AWE has employed a former **ALSU** PhD student, Dr B.C. Griffiths, to lead the laboratory. This laboratory is currently one of the main analysis suites used by the AWE to ensure the **integrity and reliability of the UK's nuclear stockpile and chemical explosives.** According to **AWE** from [C3]:

"This research has made a significant contribution to the development of a new assaying technique at AWE to enable us to monitor a variety of species at low concentrations."

Applications of laser induced plasmas by Spectrum Technologies plc

In aerospace systems, due to stringent fire safety requirements, materials used for insulators on electrical cables cannot be labelled with standard ink techniques. A company based in South Wales, **Spectrum Technologies**, pioneered the development of laser wire marking for the airline industry to circumvent this problem. Building on a long-standing relationship with Telle and his research in laser-induced plasmas, Spectrum Technologies has become a world leader in this market. Spectrum Technologies has 80 UK-based employees and 20 staff based in the USA, and its annual turnover is over £10m. From the CEO of **Spectrum Technologies** [C4]:

"… I write to acknowledge the impact that your research has had on our company over the past 10 plus years. Your expertise in pulsed solid state lasers and their applications and your research work in analytical laser spectroscopy have been of great value to us... This expertise has been critical in helping us maintain our world leading position in our core business."

Spectrum Technologies is expanding its product portfolio by developing a high-powered laser plasma technique based on infra-red laser technology to remove enamel insulation from magnetic wires by means of plasma ablation. At present, there is no product available to perform this stripping *in situ* at difficult-to-access locations typical of aerospace components. A grant has been awarded to the ALSU by the ASTUTE Wales project (under the Advanced Sustainable Manufacturing Technologies component) to conduct research aimed at developing such products [C5]. From [C4]:

"Your research in the area of laser-induced breakdown spectroscopy (LIBS) and laser-induced plasma generation now provides the basis for a whole new area for Spectrum for the research and development of a range of novel laser based products aimed at other area of materials processing and advanced manufacturing."

5. Sources to corroborate the impact

Confidential reports or documents:

[C1] **Telle, HH; Morris, GW**; "Application of TDLAS to trace gas analysis", Final Report, AWE Contract OCE0792, 2001: pp1-41; **Telle, HH**; "TDLASblue – tunable diode laser absorption spectroscopy system for the detection of NO_2", User's Manual, 2004

Letters of Support:

[C2] Managing Director, Applied Photonics Ltd, Skipton (former PhD student of the Department) www.appliedphotonics.co.uk/index.htm

[C3] Lead Scientist, Atomic Weapons Establishment (Materials Science Research Division) www.awe.co.uk/set/Materials_Science_fc0ee.html

[C4] CEO, Spectrum Technologies PLC www.spectrumtech.com/AboutUs

European Regional Development Fund Support:

[C5] **Telle, HH; Bryan, WA;** "Laser Plasma Generation for Materials Processing", Astute ERDF (EU-Wales) grant LS206, (2013) £40k