Institution: University of Oxford

Unit of Assessment: UoA7 (Earth Systems and Environmental Sciences)

Title of case study: UoA7-2: Development and application of commercial inorganic mass spectrometers and the growth of a UK SME

1. Summary of the impact

Nu Instruments is a successful mass spectrometer company set up in collaboration with geochemists at the University of Oxford. This joint effort was initially based around the development of a new kind of mass spectrometer; the Nu Plasma. Subsequent research in the UoA demonstrated the capabilities of this instrument for analysis of a large range of isotope systems, leading to its widespread use in geochemical and industrial laboratories around the world. Research in the UoA also aided in creation of new products, further contributing to growth in sales. Nu Instruments have sold over 150 instruments worldwide since 2008, while their turnover grew from £5.2M to £14.7M, and their employee numbers more than doubled to 105.

2. Underpinning research

Isotope geochemistry is based on the study of concentrations of elements and their isotopes, generally measured using mass spectrometry. Novel mass spectrometers that enable more accurate isotope measurements, or a new analytical capability, allow new scientific challenges to be addressed.

Prior to the mid-1990s, most isotopic measurements of non-volatile elements (i.e. those excluding noble gases, C, N, O and S), were performed by thermal ionisation mass spectrometry (TIMS). While powerful, this technique is limited in the range of elements for which it can provide precise isotope measurements, because of the difficulties of efficient ionisation of a thermionic source. In the mid-1990s, new mass spectrometers that combined a plasma source with multiple collectors were developed. These multi-collector ICP mass spectrometers (MC-ICP-MS) allowed precise analysis of nearly all non-volatile elements. Recognising their potential, Professor Keith O'Nions and Dr. Nick Belshaw, at Oxford University's Department of Earth Sciences, initiated collaboration with a leading designer of mass spectrometers (Dr Phil Freedman, PAF Consultants Ltd) to build an improved MC-ICP-MS; the Nu Plasma. This instrument featured innovations such as the use of fixed-position collectors, making it more analytically robust, easier to use, and yet cheaper than other designs. The prototype instrument was delivered to Oxford in 1997.

O'Nions and other University of Oxford researchers subsequently demonstrated the significant power of the Nu Plasma to the research community with a number of papers. Some influential examples include:

i. Precise and rapid measurement of Pb isotopes (e.g. Belshaw et al. 1998 [1]): Lead isotopes were an established mainstay of isotope geochemistry. This research demonstrated that the Nu MC-ICP-MS could rapidly provide measurements at higher precision than normally possible with TIMS.

ii. Measurement of transition-metal isotopes, including Fe isotopes (e.g. Belshaw et al. 2000 [3], Zhu et al. 2000 [4]): Isotope measurement of these metals had been extremely challenging but was of major interest to geochemists given the importance of these elements for earth and life processes. This research demonstrated the success of the Nu MC-ICP-MS for such measurement, and provided the first concrete indication of the huge potential of these isotope systems for the earth sciences.

iii. Measurement of Ca isotopes (e.g. Halicz et al. 1999 [2]): This research demonstrated the potential of the Nu MC-ICP-MS for analysis of lighter elements and, in a series of subsequent papers, the utility of Ca isotopes to investigate oceanographic and carbon cycle processes. Work in the UoA also demonstrated the power of Nu MC-ICP-MS analysis of Li and Mg isotopes.

iv. Measurement of U and Th isotopes (e.g. Robinson et al. 2004 [5]): This research demonstrated the potential for the Nu MC-ICP-MS to improve on TIMS for Th-isotope analysis, and the success of its innovative multiple ion-counting system. MC-ICP-MS has subsequently replaced TIMS as the major tool for U-Th geochemistry. The demonstration of successful measurement of radionuclides also contributed to recognition by the nuclear industry of the power of the Nu MC-ICP-MS.

Such papers also established the chemical separation methods and mass spectrometry protocols needed for precise isotopic measurements using the Nu MC-ICP-MS.

More recently, University of Oxford researchers have worked with Nu instruments to improve ICP mass-spectrometry design. For example, Karla Newman, working at Oxford with Prof. Alex Halliday (and collaborating with Nu instruments) helped develop prototype high-sensitivity skimmers for the Nu Plasma instrument and worked on the physics of plasma sources and extraction (Newman et al. 2009 [6]). This research has influenced design of new Nu Instruments products.

Names of the key researchers and positions they held at the institution

Prof Keith O'Nions, Chair of Mineralogy, 1995 – 2000
Dr Nick Belshaw, Senior Technician, 1995 – present
Prof Gideon Henderson, Prof of Earth Sciences, 1998-present
Prof Alex Halliday, Chair of Geochemistry, 2004-2012
Dr Karla Newman, PDRA, 2006 – 2007.

3. References to the research

The three asterisked outputs best indicate the quality of the underpinning research.

1. *Belshaw, N. S., Freedman, P. A., O'Nions, R. K., Frank, M. & Guo, Y. (1998) A new variable dispersion double-focusing plasma mass spectrometer with performance illustrated for Pb isotopes. *International journal of Mass Spectrometry* 181, 51-58. http://www.sciencedirect.com/science/article/pii/S1387380698141507 (161 citations in Scopus)
The first publication describing the Nu Plasma and demonstrating high precision and sample throughput for the frequently measured lead-isotope system.

2. Halicz, L., Galy, A., Belshaw, N. S. & O'Nions, R. K. (1999) High-precision measurement of calcium isotopes in carbonates and related materials by multiple collector inductively coupled plasma mass spectrometry (MC-ICP-MS). *Journal of Analytical Atomic Spectrometry* 14, 1835-1838. DOI: 10.1039/a906422b (70 citations in Scopus)

3. *Belshaw, N. S., Zhu, X. K., Guo, Y. & O'Nions, R. K. (2000) High precision measurement of iron isotopes by plasma source mass spectrometry. *International journal of Mass Spectrometry* **197**, 191-195. http://www.sciencedirect.com/science/article/pii/S1387380699002456 (98 citations in Scopus)
Demonstrating the power of MC-ICP-MS for analysis of iron isotopes – now a widely used application in the geosciences and elsewhere.

4. Zhu, X. K., O'Nions, R. K., Guo, Y., Belshaw, N. S. & Rickard, D. (2000) Determination of natural Cu-isotope variation by plasma-source mass spectrometry: Implications for use as geochemical tracers. *Chemical Geology* 163, 139-149. DOI: 10.1016/S0009-2541(99)00076-5 (121 citations in Scopus)

5. Robinson, L. F., Belshaw, N. S., and Henderson, G. M., 2004. U and Th concentrations and isotope ratios in modern carbonates and waters from the Bahamas. *Geochimica and Cosmochimica Acta* **68**, 1777-1789. (80 citations in Scopus)

6. *Newman K., Freedman P.A., Williams J., Belshaw N.S. and Halliday A.N., (2009). High sensitivity skimmers and non-linear mass dependent fractionation in ICP-MS. *Journal of Analytical Atomic Spectrometry* 24, 742-751 DOI:10.1039/b819065h. http://pubs.rsc.org/en/Content/ArticleLanding/2009/JA/b819065h#!divAbstract (30 citations in

Scopus)
An example of ongoing research to refine the design and use of the MC-ICP-MS, investigating non-mass-dependent effects during plasma ionization for the first time.

4. Details of the impact

The research and collaboration undertaken by the O'Nions group at Oxford led to the development of a new generation of MC-ICP-MS and of other mass spectrometers. The resulting new UK company, Nu Instruments [7] saw significant growth and sales between 2008 and 2013.

The initial collaborative venture with PAF Consultants was driven by the research requirements of the O'Nions group at Oxford. The need for an instrument that could simultaneously measure isotopes of many different elements quickly and accurately resulted directly in the prototype Nu Plasma machine, which was co-designed and built by the two organisations. To quote the founder and director of Nu Instruments, "*Without Oxford, Nu Instruments wouldn't exist.*" [8].

The 1997 Nu Plasma instrument had a number of completely new features which made it attractive to those needing high-functioning mass spectrometers in academia and industry. It was the first MC-ICP-MS that was fully double focusing with a Nier-Johnson geometry and a laminated magnet, and included the use of ion pumps. Critically, it made use of zoom optics, allowing the deployment of fixed-position collectors and switching between different elements instantaneously. These design innovations, coupled to proof of the instruments capabilities provided by Oxford University research, allowed Nu Instruments to flourish so that, by the beginning of the REF impact period, they had a turnover of £5.2M [9].

The design of the Nu Plasma was updated in 2007, to include modifications that had arisen from discussion between Oxford University and Nu researchers. For example, this generation of instrument featured adjustable slits, allowing higher resolution measurement and the more accurate analysis of some important stable isotope systems such as Fe, Ca, and Si. These design improvements led to a marked increase in sales of the Nu Plasma, from an average of 6 per year in the previous five years to an average of 9 per year in the period 2008-2012 [9].

The Nu Plasma remains a major-selling product for Nu instruments and has contributed to the continued success of the company since 2008. High sales are aided by the demonstration, by Oxford University scientists, of the successful research application of the instrument to a wide range of isotope systems. This research also helped Nu Instruments sell the Nu Plasma into new analytical markets beyond geochemistry (for example, the nuclear industry; [9]).

Nu Instruments subsequently developed four further mass spectrometer designs, two with the active involvement of Oxford University scientists. The Astrum is a new glow-discharge mass spectrometer developed using the expertise of Karla Newman, who initially worked for Oxford University's Department of Earth Sciences and collaborated in several research areas with Nu Instruments. In October 2007 she transferred to Nu to work on the Astrum instrument, the first of which was shipped in 2010. This instrument has enabled Nu to enter a new customer base in industrial materials characterisation [9]. Nu Instruments have thus benefited by drawing on the highly-specialised research and development skills of staff from Oxford University. Oxford University staff (Belshaw) also contributed to software development for the AttoM instrument, launched in 2005 and sold to more than 24 customers in academia and industry during the REF period [9]. Belshaw now provides consultancy services to the company on software and product design [10].

Between 2008 and 2012 Nu Instruments sold a total of 157 instruments around the world (including Europe, Australasia, China and the USA). Oxford University contributed to the development of 55% of these. Nu has grown significantly since 2008 and has a thriving company base in Wrexham, North Wales, as well as being serviced by offices in five countries. Its turnover has nearly trebled from £5.2 million in 2008 to £14.7 million in 2012, and it has more than doubled its number of employees from 45 in 2008 to 105 in 2013. The success of the company, and its importance to the local economy, was recognized by the local MP, who selected Nu Instruments as the best company to represent manufacturing innovation within their constituency [11].

Aside from commercial success, the development of their products has revolutionized inorganic

mass spectrometry and enabled new discovery in a wide range of academic and commercial disciplines. Nu Instruments has become an internationally leading mass spectrometry company, having started through collaboration with Oxford University, and now continuing to benefit from research undertaken at Oxford University.

5. Sources to corroborate the impact

7. Nu Instruments: http://www.nu-ins.com/index.php/about-us
   Verifies company start date and instruments on sale.
8. Nu Instruments Director.
   Letter on file outlining history of involvement with Oxford researchers, and quoted above.
9. Nu Annual instrument sales figures, including those to the nuclear and materials industries, plus annual turnover. Statement on file from Administration Manager, Nu Instruments.
10. Oxford University Research Associate can confirm consultancy arrangements on request.
11. Nu Instruments press release March 2012: Made by Britain: The Associate Parliamentary Manufacturing Group (APMG) requested each Member of Parliament to select a company that they felt best represented manufacturing innovation within their constituency. The Member of Parliament for Wrexham, Ian Lucas MP, selected Nu Instruments. See (http://www.nu-ins.com/index.php/news and http://www.policyconnect.org.uk/apmg/made-by-britain/nominations/mass-spectrometers-nu-instruments-ltd).