SUERC RESEARCH STRATEGY 2014-2024

Strategy to Develop SUERC as a World-Leading Centre

*Our **vision** is a 10 year plan to expand and consolidate SUERC as a pre-eminent centre of excellence for the application of isotopic techniques in Earth, Environment and Biochemical research. SUERC will lead and develop new applications across its science themes. Equally, SUERC will be the partner of choice for a broad community offering access to the highest levels of analytical capability and associated expertise to deliver a cutting-edge research agenda.*

Our **strategy** builds on the evolution of successful existing research activities, diversification into new areas and establishment of new capabilities based on novel techniques and technologies. The strategic themes are:

- Novel Stable Isotope Techniques
  - *Clumped Isotope Geochemistry*
  - *Marine Nitrate N & O Isotopes*
  - *Stable Isotope Ecology and Archaeology*
- Advanced Carbon Cycle Analysis
  - *Dissecting the Carbon Cycle*
  - *Next Generation Oil and Gas*
  - *Compound Specific (Radio)carbon and* in situ *^{14}C*
  - *Positive Ion Accelerator Mass Spectrometry (AMS)*
- Seamless "Anthropocene" to Deep Time Geochronology
  - *Chronology for Geology and Archaeology*
  - *Solar System Chronology*
- Mass Spectrometric Imaging of Cell Function in Biomedicine
  - *Metaprobes - the functional significance of gut microbiome in human health*
  - *Nano-SIMS measurement and imaging of individual cell function in chronic disease*

1. Research Strategy: World-Class Capabilities

A core strength of SUERC is the development of new and improved analytical capabilities. The acquisition of the MAT 253 Ultra, the second instrument worldwide and the first in Europe capable of making a wide variety of accurate and precise 'clumped isotope' measurements, will initiate a new field of "isotomics" – the "omics" of isotope geochemistry. We are one of the few laboratories worldwide capable of marine nitrate N and O analyses and will improve the sensitivity of the technique and make it more user-friendly, thereby facilitating its use by a wider community. We are a major provider of isotope data to the ecological and archaeological communities who have limited local capability and we will expand these activities. The diversity of isotopic techniques available at SUERC put us in an advantageous position to exploit opportunities in characterizing environmental gases and crustal fluids associated with unconventional oil and gas exploitation. Operation of the AMS in positive ion mode will achieve a step-change in sensitivity becoming the methodology of choice and making tandem AMS effectively obsolete for radiocarbon. Increased sensitivity will facilitate ^{14}C measurements at compound specific level, for exposure dating and as a sensitive tracer for source apportionment of atmospheric gases. Using newly acquired noble gas mass spectrometry and by re-establishing a capability in U-Pb geochronology we aim to achieve (i) seamless Earth System chronology from tens to billions of years, and (ii) hitherto unanticipated precision to resolve "deep" (10^8 year) geological time on the (10^4-10^5 year) timescales of the orbital periodicities that have dominated climate change over the past 500,000 years. As one of the top Ar dating laboratories worldwide, we intend to continue to diversify into extra-terrestrial chronometry. Using techniques that are better-known to the Material and Earth Science communities, we will provide measurement and imaging of cell function combined with the application of stable isotope metaprobes to explore the functional significance of cell dynamics and molecular interactions in chronic disease and human health.

2. Research Strategy: Addressing Major Challenges in Diverse Disciplines

Overall, we will develop new technologies and engage with the wider Earth, Environmental, Archaeological and Biomedical Science communities to promote applications aimed at key grand challenges. The addition of novel techniques to our existing areas of expertise will allow us to assume a pre-eminent position within the oil and gas, marine science, planetary science, climate change, natural hazards, ecology, palaeobiology and biomedical communities. Building on an established ethos of collaboration we will combine frontier applications of new technology in our own areas of excellence with new applications across a diverse range of sub-disciplines led by our collaborative partners.

Clumped isotope Geochemistry is anticipated to offer new constraints on palaeotemperatures of relatively low temperature Earth System processes e.g. changing seawater temperature and hydrocarbon maturation temperatures. Clumped isotopes offer proxies for past climate change and novel insights into areas as diverse as atmospheric chemistry and evolutionary palaeobiology. Such studies are in their infancy but, with appropriate instrumentation already funded, we intend to assume a leading role in this new sub-discipline.

SUERC leaders – Ellam, Newton & new appointment
EU collaborators – Butler, Cravan, Gilfillan, Harley, Haszeldine, Hinton, Tudhope, Wilkinson, Wood
GU collaborators – Cusack, Gauchotte-Lindsay, Kamenos, Phoenix, Waldron

Marine Nitrate N & O Isotope data are needed to understand better the behaviour of nitrate (NO_3^-) in the marine environment and constrain the N-cycle. Nitrate is a limiting nutrient in many areas of the ocean and the supply of nitrate from the deep ocean is an important control on productivity and carbon export from the surface ocean. Understanding the nitrate inventory is therefore critical to carbon cycling and hence key to predicting the oceanic response to rising carbon emissions. Understanding the Earth system response to anthropogenic global warming is clearly a high-level priority. Such knowledge will underpin the business responses that will generate maximum economic benefit from environmental science. Hitherto, this sub-theme has been driven by a member of staff who recently retired and implemented by SUERC Technicians and EU Ph.D. students. Adding academic expertise in this area is critical to maintaining the world-class capability.

SUERC leaders – Ellam & new appointment
EU collaborators – Ganeshram, Henley
GU collaborators - Waldron

Stable Isotope Ecology and Archaeology will expand the use of stable isotope tracers providing spatial and temporal resolution in ecological systems and archaeological contexts to understand changes in habitat, migration patterns and dietary tendencies. In Ecology, such data contribute to our understanding of habitats that are vulnerable to over-population of man-kind, competition for scarce resources and global change. In Archaeology, stable isotopes are increasingly being used to reconstruct dietary and other lifestyle factors. SUERC has pioneered many Ecological applications through the NERC Life Science Mass Spectrometry Facility and the SUERC Radiocarbon laboratory has diversified into stable isotope applications. Now we seek to exploit this leading role by placing these activities at the heart of our new research strategy.

SUERC leaders – Ascough, Cook, Newton (NERC LSMSF) & new appointment
EU collaborators – Dugmore
GU collaborators – Adams, Furness, Naylor, Waldron

Dissecting the Carbon Cycle to understand the source, fate and age of carbon is the key to reconstructing past environments, elucidating present biogeochemical cycles, and predicting future climatic change. The NERC RCF(EK) has developed novel methods for environmental sampling for radiocarbon analysis. A group of C-cycle SUERC scientists is exploring the application of catalytic hydropyrolysis (HyPy) to environmental matrices. Hydropyrolysis opens up important applications where conventional approaches fail; the focus of the proof-of concept work has been to quantify stocks of highly recalcitrant 'Black Carbon" (recognised as a key substance in the IPCC AR4 report), but HyPy also opens research avenues in geobiological studies related to ancient biomarker detection (e.g. recording the earliest fossil evidence of animals), oil basin reservoir filling history, and detailed characterisation of macromolecular carbon in meteorites. Our ambition is to push current boundaries of understanding by integrating novel analytical capabilities to quantify key uncertainties in global carbon dynamics.

SUERC leaders – Ascough, Bryant (NERC RCF), Garnett (NERC RCF)
EU collaborators – Attal, Dugmore, Ganeshram, K Heal, M Heal, Johnson, Newton
GU collaborators – Cusack, Lee

Next Generation Oil and Gas – Led from the SUERC noble gas and stable isotope laboratories we are reinstating with significant improvement the capability to measure environmental methane $\delta^{13}C$ and δD. Methane is a potent greenhouse gas and measuring its abundance and isotopic composition to constrain its source is of significant interest. SUERC's ability to combine $\delta^{13}C$ and δD with other isotopic tracers (e.g. the noble gases and clumped isotopes) gives us a spectacular advantage. There is also an immediate opportunity arising from controversial proposals to exploit shale gas or coal-bed methane with an urgent need to establish the chemistry of natural drinking water before any exploitation that might damage supplies.

SUERC leaders – Stuart, Boyce (NERC ICSF)
EU collaborators – Gilfillan, Haszeldine, Wilkinson
GU collaborators – Younger, Waldron

Compound Specific Radiocarbon analysis uses various methods to divide organic samples into their constituent molecular species and delivers isotopic information for each individual species. Compound specific $\delta^{13}C$ has become a routine analysis in many laboratories. We have been developing a technique that couples compound specificity and AMS with the objective of generating ^{14}C data on individual molecular fractions to provide chronological and/or tracer information in carbon cycle studies, carbon capture and storage, and environmental monitoring of petroleum-derived compounds. The NERC Radiocarbon Facility leads the SUERC effort in this area working closely with the SUERC AMS Facility.

SUERC leaders – Ascough, Bryant (NERC RCF), MacKinnon
EU collaborators – Attal, Dugmore, Ganeshram, Gilfillan, Newton
GU collaborators – Lee, Toney

***In situ* ^{14}C** uses ^{14}C as a cosmogenic nuclide for surface exposure dating. With a half-life of 5730 years, ^{14}C is entirely complementary to the other surface exposure nuclides that are regularly measured by AMS at SUERC (^{10}Be, ^{26}Al and ^{36}Cl) which all have much longer half-lives. SUERC is the only UK institution routinely preparing samples and making AMS measurements for these nuclides and it would therefore entirely appropriate that we develop further capability for *in situ* ^{14}C. The SUERC radiocarbon laboratory has made *in situ* measurements but the method is currently mothballed. Alternative sample preparation methods involve methodologies imported from noble gas geochemistry where SUERC has substantial expertise.

SUERC leaders – Cook, Stuart
EU collaborators - Hein
GU collaborators – Bishop, Lee

Positive Ion AMS aims to meet the requirement for small sample sizes in these advanced radiocarbon applications The 250kV single stage accelerator mass spectrometer (SSAMS) can accelerate positive ions as well as conventional negative ion operation. Positive ion operation promises substantially enhanced ion yield and possibly orders of magnitude decrease in sample requirement for ^{14}C and other nuclides. The SUERC AMS team is currently developing this sub-theme in association with industrial collaborators.

SUERC leaders – Freeman, Shanks, Xu
EU collaborators - Attal, Dugmore, Ganeshram, Newton
GU collaborators – Fabel, Bishop

Chronology for Geology and Archaeology strives to establish continuous chronology from timescales of decades, through millennia to millions and billions of years. A key contribution has been the development of noble gas mass spectrometry to enable Ar-Ar dating of much younger samples into the realm of radiocarbon i.e. < 50 ka. This greatly complements existing SUERC capabilities in ^{14}C, U-Th and luminescence dating of Quaternary samples. In addition, with anticipated developments in mass spectrometry, we will extend our capabilities in ^{3}He and ^{21}Ne exposure-age dating and work towards better precision and younger age capability with ^{10}Be.

High precision geochronology in geological "deep time" has become a reality in recent years led largely by the international Earthtime project which resolved many of the calibration issues between laboratories and between different chronometers. New developments in noble gas mass spectrometry are facilitating Phanerozoic ages with precisions that are comparable to the period of the eccentricity astronomical cycle (i.e. 100,000 years) and approaching that of the obliquity (41 ka) and precessional (21 ka) cycles. Thus, we are poised to enter an era in which combined U-Pb and Ar-Ar will offer the geochronological gold standard. There is an opportunity to complement our Ar-Ar dating capability by re-establishing a capability in U-Pb dating based around a new ultra-clean laboratory that can support the sample preparation requirements for modern analyses by thermal ionization (TI) and inductively-coupled plasma (ICP) mass spectrometry (MS).

SUERC leaders – Ellam, Freeman, Mark, Rood, Sanderson, Stuart, Xu
EU collaborators – Attal, Craven, Fitton, Geibert, Harley, Hinton, Kirstein, Robertson, Sinclair, Tait
GU collaborators –Bishop, Dempster, Lee

Solar System Chronology is a new research theme for SUERC based on established expertise in high-precision $^{40}Ar/^{39}Ar$ geochronology. Specific project goals have been to determine the timing of fluid-rock interaction in the Martian crust to assess the planets past potential for habitability, reconstruct the breakup history of primitive (chondrite) meteorite parent bodies such as Vesta, and to examine the Late Heavy Bombardment of the Solar System 4.1 billion years ago, evidence for which is provided by lunar meteorites and the NASA Apollo Mission samples. There is now a growing Planetary Science Research Group at SUERC. Its goal over the next five years is to build a reputation for excellence and expand both the analytical capability and the size of the group to maintain momentum in securing research funding. Ultimately though, the place to do planetary science has to be on the planets. Recently, the UK Space Agency has commissioned a consortium led by SUERC to carry out KHRONUS a desk study into the feasiblility of *in situ* $^{40}Ar/^{39}Ar$ geochronology on rocky planets, moons and asteroids. If KHRONUS succeeds, the next stage will be a multi-million pound effort to develop a probe that can be flown on a planetary rover comparable to Mars Curiosity.

SUERC leaders – Ascough, Mark, Morgan, Morrison
EU collaborators – Hinton
GU collaborators - Lee

Metaprobes or stable isotope labelled molecules synthesized through chemical or biological procedures are applied to study human biology in health and disease. In biomedical research, we offer specialist expertise and analytical capabilities emphasizing techniques that are not yet widely available to medical science. Our unique approach of using targeted tracers coupled with high sensitivity isotopic measurements will provide new insights into diet and lifestyle (environmental) related risk factors in human health and disease. With a focus on chronic conditions including type-2 diabetes, gastro-intestinal cancer and obesity, we will contribute to some of the major medical challenges within, and increasingly beyond, the Western World.

SUERC leaders – Morrison, Preston
EU collaborators – Fearon, Ross, Walker, Andrew
GU collaborators - Milligan, Edwards, Malkova, Gerasimidis, McMillan

Nano-SIMS measurement and imaging of cell and sub-cellular function in chronic disease has great potential by coupling stable isotope probing with high resolution imaging. The Cameca Nano-SIMS 50L secondary ion mass spectrometer (SIMS) has spatial resolution down to 50nm allowing sub-cellular imaging. In our studies on the function of the gut microbiome in health and disease the ability to couple phylogenetic identity with metabolic function (using isotopic labelling) will elucidate the role that the gut microbiome plays in protecting against disease. We envisage Nano-SIMS taking isotopic or elemental labeling experiments to a new level of sophistication through the ability to image and measure the functional role and identify of individual cells. Nano-SIMS measurements will allow biologists to image and quantify human and bacterial cell turnovers and follow the fate of individual molecules within and between cells. We anticipate significant impacts in understanding the functional importance of cell-cell interactions and how environment influences bacterial and host cell function in chronic disease and health.

SUERC leaders – Morrison, Preston
EU collaborators – Walker, Andrew, Craven, Harley, Hinton, Saunders. Wood
GU collaborators – Barrett, Edwards, Burchmore, Cusack, Phoenix

3. Strategic objectives

OBJECTIVE	ACTION	MEASURE	TIMESCALE
ACADEMIC			
1. Enhance capability of the Centre and make it the partner of choice for a variety of challenging analyses and measurements	Planned recruitment process from international talent pool, rigorous Early-Career Development and P&DR objectives	Achievement of rigorous P&DR objectives	Annual P&DR cycle with 5 years or REF cycle review
2. Increase quality and maintain quantity of research outputs	Monitor and mentor against target expectations	REF-style assessment through P&DR	Continuous and on-going
FINANCIAL			
3. Widen funding base & reduce exposure to individual stakeholders	Closely link new initiatives and appointments to anticipated funding	Reduce reliance on NERC Facility funding to 25% and increase EU funding to 15% of £7M target	Annual review
4. Maintain proportion of commercial income and increase commercial overhead while increasing academic engagement	Enhanced marketing effort and development of staff with dominantly commercial income	Increase commercial income to £2.3M and overhead contribution to 30%	Annual review
OTHER			
5. Ensure infrastructure remains at the cutting edge	Enter more capital equipment grant competitions, "white board" equipment priorities	Fixed asset register	Responsive to opportunity
6. Attract more quality partners, enhance visibility and reputation	Better marketing and greater role in scientific community	Regular community events	Two-yearly