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Dalton Nuclear Institute

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DALTON CUMBRIAN FACILITY NEWSLETTER

February 2022

WELCOME

Dear friends, colleagues and collaborators,

It is a great pleasure to share with you some of the recent developments at the Dalton Cumbrian facility in our Winter newsletter and to take the opportunity to wish you all a happy and fruitful new year. In one of my recent walks on St. Bees beach, gazing heavenwards I was captivated by the Milky Way, spread across the night sky – I began to reflect on the space-related research of some of our recent visitors. We were pleased to welcome Louise Hirst's group from the University of Cambridge, who have been using our accelerators to examine the effects of ion bombardment on semiconductor structures eventually bound for use in space missions. Again, we were pleased to welcome Nigel Mason's Kent University and Anita Dawes' Open University groups who joined us to make measurements of ion-irradiation of Astrochemical Ices, looking at spectroscopic signatures of the chemical changes the ions induce.

With several new users in these and related areas, we have decided to rename our 'Environment' stakeholder group to be the Planetary, Environment, Atmospheres and Space stakeholder group, or PEAS for short. This is perhaps a good time to remind you that we run four stakeholder groups with the themes of Chemistry, Materials, Medical/Bio and now PEAS. You can subscribe to any/all of these simply by emailing Amy Johnson (amy.johnson-2@manchester.ac.uk) saying which groups you would like to join. This will then allow us to send you only information of interest. This is particularly relevant as we start to plan a series of stakeholder meetings this summer.

When doing outreach for school visitors I usually open with a slide giving several statements, with the visitors being asked to decide which of the options ***does not*** describe DCF. The two options most usually chosen are *A time-machine* and *A space ship to explore other worlds*. In the talk, I have already mentioned our capabilities for accelerated radiation aging of reactor-facing materials, which I then characterise as DCF being a time-machine. Perhaps, with the growth of PEAS at DCF, I will need to rewrite this talk as DCF is increasingly becoming a spaceship as well as a time-machine, helping explore just a few of the other worlds I was gazing at on St. Bees' beach. I only wish it was a Tardis as well, so we could fit all of the wonderful science going on in at once – well hopefully we can do a little of this in our series of user-meetings.

Fred Currell

Fred Currell
Director of DCF

Lian Murdoch

Lian Murdoch
Editor

EQUIPMENT DEVELOPMENT

New Equipment: Setaram LabsysTM Evo for Thermogravimetric (TGA) / Calorimetric (DSC) analysis coupled with a Hiden EGA Mass Spectrometer

Recent addition to the DCF's world-leading research infrastructure is an advanced analytical system capable of delivering both qualitative and quantitative information about thermal effects in materials in correlation with their structure and composition. The procured TGA/DSC/MS system has been recently installed at DCF will serve as a powerful tool for characterization of radiation-induced decomposition and damage processes in a wide range of nuclear materials, including: (a) organic polymers used in nuclear industry; (b) advanced ceramic materials and (c) structural metal alloys for future reactor build. Combination of thermogravimetry/calorimetry with mass spectrometry detection enables great versatility of the technique that spans over quantitative content analysis, kinetics of decomposition processes, identification of volatile and non-volatile degradation products, characterization of adsorption and desorption of gases and moisture, as well as determination of crystallization/melting point, heat capacity, glass transition and phase transformation.

The TGA/DSC/MS apparatus will enable to study systematically the occurrence of phase transformations in advanced nuclear materials due to radiation at the relevant temperatures. The construction and operation of future fission and fusion reactors require that we now develop novel structural materials that can safely operate under very demanding conditions of temperature (>400°C) and radiation doses. Neutron irradiation on structural materials results in the generation of lattice defects (vacancies and interstitials), due to the displacement of atoms from their equilibrium lattice positions by the neutrons generated in the nuclear fission or fusion reaction. The evolution of those defects leads to the formation of (meta-) stable nanostructures, such as staking fault tetrahedra, dislocation loops and cells, nano-cavity arrays or nano-clusters. These will alter the stability of the phases that provide the material with the desired mechanical integrity. Those nano-scale structural defects can also constitute preferred nucleation sites for the formation of unexpected new phases during the service life of the material under irradiation conditions.

Finally, the mass spectrometer on the analytical end creates an extremely robust tool for investigation of decomposition patterns in irradiated organic polymers. For example, studying evolution of the volatile fragmentation products from irradiated polymers will yield valuable information about radiation-induced degradation pathways, while the shift in glass transition temperature will be indicative of the change in the degree of crosslinking due to radiation.

TECHNICAL SPECIFICATIONS
Temperature range: up to 1600 ºC; temperature accuracy: ± 1°C; sample volume: <100 μL; calorimeter sensitivity: 0.1 J/ºC

ROBOTICS FOR EXTREME ENVIRONMENTS LABORATORY

The Robotics for Extreme Environments Laboratory (REEL) is a sister site to the Dalton Cumbrian Facility and is currently based in Cleator Moor, Cumbria.

It's an exciting time for the research team over at REEL as they prepare to move into a brand new facility in Whitehaven, RAICo One. A significant step was made with the delivery of the water tank. The water tank is an important resource for the team as it is used as a testing and demonstration space for submersible vehicles and ROVs.

RAICo One is a collaborative facility that has been set up as a partnership between The University of Manchester, UKAEA, NNL and Sellafield Ltd that will allow researchers from academia to work directly with robotics experts from industry.

The facility offers access to mock-ups and robotic equipment to enable researchers to address nuclear decommissioning challenges. Equipment includes an array of submersible vehicles and underwater manipulators, together with a pond equipped with an underwater and above water Vicon positioning system, where aquatic based systems can be tested. In addition, there is a wide-range of sensors available including thermal cameras, radiation detectors and simulated radiation sources that are ideal for testing robot autonomy in radiation environments.
RAICo One is part of the National Nuclear User Facility for Hot Robotics (NNUF-HR). This is an EPSRC funded project to support UK academia and industry to deliver ground-breaking, impactful research in robotics and artificial intelligence for application in extreme and challenging nuclear environments.

Professor Barry Lennox commented; "the RAICo One facilities provide a unique environment where researchers from academia can work directly with engineers and operations staff from across the NDA estate and the nuclear supply chain, to ensure that the robotic systems they are developing address real industrial challenges and can exploit the direct route to industry deployment that is being established".

** Top right photo supplied by Sellafield Ltd*

RADIATION CHEMISTRY REVIEW PAPER

Those of us working on radiation chemistry were recently invited to contribute to a special edition of the journal Applied Sciences.

Our manuscript, entitled *Resurgence of a Nation's Radiation Science Driven by Its Nuclear Industry Needs*, reviews ongoing research in key applications of radiation chemistry, some of which extend beyond the nuclear industry. One of our longest-standing areas of research is in the radiolytic production of gases from water that is in the presence of metal oxides. In the early days, efforts were concentrated on constructing radiation tolerant, gas-tight vessels that allowed us to sample the head-space, with subsequent analysis using gas chromatography. Recent developments in gas probe technology have provided a new means of detecting hydrogen gas that can provide rapid, on-line analysis of the amount produced. Work is underway to develop a similar technique for analysing oxygen gas concentrations. These developments will enable us to explore the rich dynamics of radiolytic production, depletion and radiation ageing of samples of relevance to both Magnox sludge and to the storage other metal oxides.

Work that is complementary to the sensing of gas from radioactive waste materials involves the interplay between materials chemistry and the properties of a material. For waste immobilisation, different glass compositions have been irradiated with ion beams to determine the degree of swelling under certain conditions which can then be related to structural changes. Further experiments will probe the effect that radiation has on dissolution of the wasteform and investigate the radiation response of crystalline inclusions within the waste. These experiments will help understand the efficacy of vitrification in immobilising waste over periods relevant to geological disposal. Another aspect of materials chemistry involves polymers. Both 3D printing and the application of strippable decontamination coatings are burgeoning areas of research for the industry. Experiments at DCF can determine which polymeric materials should be used under given conditions, and uncover the maximum dose rate or total dose that a material can be exposed to while still performing within defined parameters.

Aside from waste management, our bespoke fluid recirculation loop allows us to investigate water radiolysis under the extreme conditions of high temperature and pressure. The recirculation loop can be used with both the particle accelerator system and the gamma irradiator so that we can separate out the effects of different radiation fields found within a nuclear reactor. For Light Water Reactors, our results can be used to create accurate models of the reactor chemistry while for Pressurised Water Reactors, the introduction of zirconium alloy to the reaction vessel allows us to understand radiation-enhanced corrosion of fuel cladding. Radiation chemistry in aqueous systems also has applications to healthcare. In cancer therapy, we investigate the molecular mechanism whereby administering certain dietary supplements in the weeks prior to treatment with radiation may limit damage to healthy cells. The redox conditions produced during radiation therapy are also produced during normal metabolic processes hence, radiation chemistry studies can be used to understand the role of free radicals in cell death and survival. In other cancer therapy applications, work is underway to adapt our particle accelerator system to deliver a high energy neutron beam. This project (known as Dalton Neutron User BEams or DANUBE) will be vital for probing the effects of neutrons that are produced during proton therapy. An additional development, which has applications to all of our research areas, SMall MOdular Radiation Experimental Systems (SMORES), will lead to automated repeatable experiments that will increase the volume of research at DCF.

STUDENT PROFILES

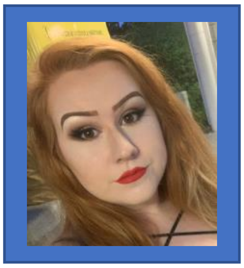
Arthur Purser

I am an undergrad joining Dalton Cumbrian Facility as part of the MiRACLE collaboration to develop in-silico investigations of fast cytotoxic reactivity around radiosensitisers in augmented therapy. I have worked in a supporting role in the NHS and witnessed first-hand the impact science and technology can have on people's quality of life; I left that job to pursue chemistry. In one way or another I've always been fascinated by the dynamics of complex systems and have become especially interested in the physicochemical dynamics of disease states.

Edwin Hsu

My project title is “Strength and Surface Microstructure of Additively Manufactured Metal Components, both as Manufactured and after the Impact of Radiation/Corrosion Environmental factors, a study into how highly radioactive conditions can affect novel additively manufactured materials”. As additive manufacturing becomes a more mainstream method of building and conducting repairs and maintenance it’s important to understand how the materials are going to stand the test of time under harsh conditions in the nuclear industry. I’ve always had something of an interest in 3D printing, one of my friends had one and I always listened to him complaining about it but I never realised just how advanced and widespread it had become. Coming out of my final year doing physics at Southampton University, this coupled with a growing interest in the nuclear industry from a final year module looking at real world nuclear and I thought this looked like a very intriguing topic to delve into further.

Elen Clayton



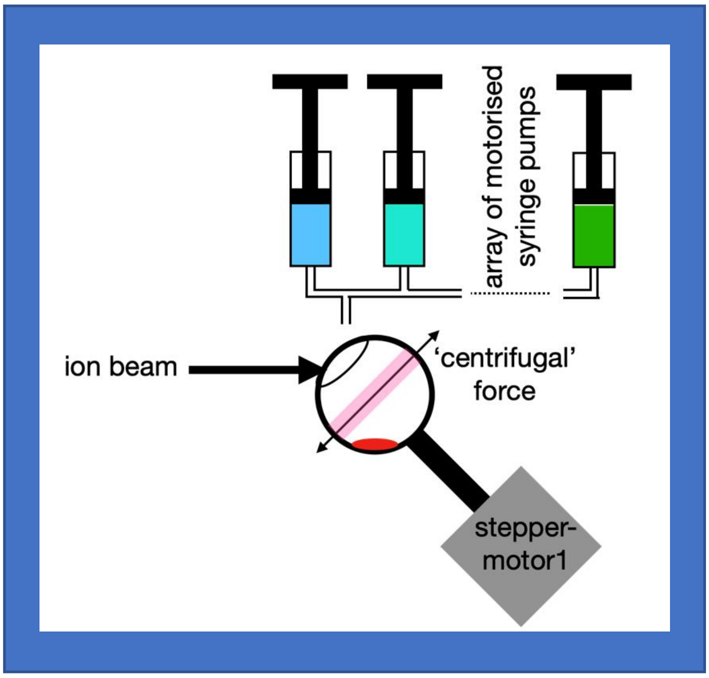
My PhD project focuses on the designing and building of a universally applicable modular flow loop in order to irradiate mixed phase solvent systems, to enable investigation into the system’s degradation products. I studied at The University of Manchester prior to this and, in June 2021, graduated with an integrated Master’s degree in Chemistry. My final project, with Dr Aliaksandr Baidak as my supervisor, explored the degradation effects of gamma radiation on acetohydroxamic acid/nitric acid solution. I chose this PhD as I wanted to continue research with Dr Baidak on nuclear fuel cycles, as they are incredibly important in the global effort to move away from fossil fuel derived energy. I hope to pursue a career in research and development and this PhD will provide invaluable experience and allow me to work with state-of-the-art facilities at Dalton Cumbrian Facility.

PROJECT SPOTLIGHT

'Wineglass' Sample Handing Environment
Mel O'Leary

We have developed a new sample holder, which allows the irradiation of small volume liquid samples it has been demonstrated with ferrous sulfate dosimetry in the recent paper *Resurgence of a Nation's Radiation Science Driven by Its Nuclear Industry Needs* .

The sample holder has significant potential application in experiments involving ion irradiations of a wide range of liquids, particularly biological targets.



This sample holder is a 3D printed in polypropylene spherical shaped open topped vessel with a stem. This stem allowed the attachment of an electric motor to the sample chamber.

A liquid sample was poured into the sample holder, which was then spun at around 3000 RPM, while the sample is irradiated by an ion beam. Thus, the liquid sample was held at the equator of the sample holder by centrifugal force, during the ion irradiation. The benefit of this system is that it allows small amounts of sample to be irradiated in thin layers in a well-stirred environment. Automated sample changing and a clean-hood are future upgrades we envisage.

NNUF National Nuclear User Facility

UKNIBC UK NATIONAL ION BEAM CENTRE

HENRY ROYCE INSTITUTE