DRAFT ONLY – PROPOSED INSTRUMENTATION IN TABLE 1 IS NOT FINAL AND MAY BE SUBJECT TO CHANGE.

The Imaging Solutions Centre

On the 14th July 2008 the Department for Innovation, Universities and Skills (DIUS) announced a £397 million investment portfolio in new scientific infrastructure. This announcement included the earmarking of £24M for a **new Imaging Solutions Centre** to be built on the Harwell Science and Innovation Campus.

The Imaging Solutions Centre (ISC) is envisaged as a new user facility on the RAL-Harwell campus, for UK researchers from both industry and academe. The ambition is to provide **new, world-class imaging capabilities**, and enhanced access to the imaging techniques provided by the existing large-scale facilities, such as the Diamond Light Source, the ISIS neutron facility and the Lasers for Science Facility. The centre will be multidisciplinary, and the expected users will include life scientists, materials scientists, physicists, engineers and medical scientists.

The centre will incorporate new hardware and software which will augment that available at Universities and other Research Laboratories. It will thus bring together:

- Leading large-scale radiation sources (ISIS, Diamond Light Source, Lasers etc.)
- Leading laboratory-scale imaging techniques
- Advanced visualization & data interpretation software
- Imaging R&D
- Leading detector technology – in partnership with the STFC Detector Systems Centre
- Computational modelling - in close collaboration with the STFC Hartree Centre
- Imaging 'users' & imaging 'providers' to define a development path

The ISC will also form close links to other imaging centres across the UK and overseas, and should be seen as one of a set of UK centres in the field of advanced imaging techniques.

Imaging – the opportunity

Within the experimental sciences, imaging the subject under study is one of the most powerful tools at our disposal. Advances in imaging science and technology have progressed at an accelerated rate over the last fifty years, uncovering increasingly detailed structural information ranging from the first visualisation of individual atoms by field ion microscopy to the development of clinical imaging techniques such as MRI. Imaging sciences are set to undergo further rapid technological development with advances in illumination sources, new detectors and software techniques. This will lead to the visualisation of smaller structures, at higher resolution, in 3-dimensions, and elucidation of dynamic events in living cells. A recent special edition of **Nature** (June 4th 2009) highlighted this topic, and pointed out the scientific opportunities within the imaging fields.

The ISC Vision

To ensure that UK science can participate at the leading edge of these new techniques, the STFC will create a **new National User Facility – the Imaging Solutions Centre (ISC)** - on the Harwell Science and Innovation Campus.

The key role of the ISC will be to bring together those imaging technologies and skills that require a National Facility for their successful exploitation. It will thus link the current imaging capabilities (and those under development) at the Diamond Light source, the ISIS neutron Facility and the Central Laser facility. To these capabilities it will add new advanced laboratory-scale instrumentation (such as electron microscopy, and super resolution optical microscopy) which will have close synergies with the existing national facilities.

This powerful combination of imaging modalities on the same site will enable significant advances in imaging sciences.

Imaging techniques cover an enormous spectrum in both methods and application. Some techniques (such as crystallography, small angle scattering or reflectometry) provide nano-scale structural images that are averages of the sample under study. Others (such as electron and optical microscopy) provide images from single subjects.

A central ambition of the new centre is to enable ***different imaging techniques to be combined in tackling a particular scientific problem***. As an example, the wide range of integrated imaging techniques - all available on the same site - will enable studies to be made that encompass **a wide range of length and time scales**. This new ability - to study a living cell, a new material or an engineering component - with a combination of leading imaging technologies will provide a unique facility for both UK industry and academe.

A further aim of the ISC is that it should provide imaging expertise – to enable ***new users to find solutions*** to their own problems. It is recognised that many industrial and scientific problems will require a range of imaging techniques to be deployed in their solution. The Imaging Solutions centre will therefore act as a 'one-stop-shop' which will provide the skills necessary enable such new problems to be tackled successfully.

The aim of combining multiple imaging techniques, and in facilitating 'non-expert users' will naturally require ***new imaging software.*** One of the key provisions of the ISC will therefore be in the area of imaging software, since this is often one of the areas that inhibits the full exploitation of the techniques available.

In addition, the location of the ISC, and its in-house expertise will enable the development of new imaging technologies, and techniques.

In conjunction with other Imaging Centres, the ISC will aim to be at the forefront of imaging science and analysis, and will integrate research across the spectrum - from blue sky science to translation, from atomic level to whole body imaging.

The ISC Description

The ISC has £24M of capital earmarked for its construction, and we are currently planning on a centre that will hold between 50 and 70 staff and visitors, and include ~1000 m^2 of laboratory accommodation built to a high environmental specification. It is scheduled to be completed by the Spring of 2012.

Following consultation with UK scientists in different imaging fields, the need for investment in a number of leading-edge imaging technologies has become apparent. The instruments recommended for inclusion within the ISC are currently unavailable within the UK, and are listed in Table 1 below. The techniques selected are those which require a **national facility** for their effective delivery, and which will have a **strong synergy** with the existing imaging capabilities on the

RAL site. Their inclusion should enable the UK to participate on equal terms with the best in the world.

It should be noted that imaging software has been included within Table 1. It is widely recognised that this is a key requirement, and will be developed primarily to support the imaging instruments within the ISC and other STFC facilities.

One of the main aims of the ISC is to provide a centre at which a range of techniques may be deployed to study the same problem, and thus the equipment should be seen in the context of the existing imaging techniques available on the RAL campus (Table 2). In Table 2 we have listed the 'direct' imaging instruments – to which may be added the even larger list of ' indirect' imaging (reciprocal space) beam-lines. The synergistic use of direct and indirect imaging will be a particular feature of the ISC. The creation of the ISC will thus encourage close interaction between the different imaging modalities available on the RAL/HSIC site, and enhance their interoperability.

It should be stressed that the equipment listed in Table 1 is intended to provide a 'nucleus' for the creation of the future ISC, and is not intended to be the final instrument complement. The ISC building will be large enough to enable further instruments to be co-located in the ISC, and the initial LFCF funding has been used to provide the key new instrumentation that will enable the ISC to make a successful start in its new role.

Aims and objectives

The specific scientific aims of the ISC will develop with time under its own Director and Management Committee, but some of the likely objectives can already be identified:

- Play a major role in solving the grand challenges for imaging scientists: of software, resolution, speed and *in vivo* imaging;
- Provide a portal for interaction with the industry and accelerate translation where appropriate;
- Develop new facilities at the ISC including cryo-electron microscopy , E-TEM, and new optical super resolution techniques which complement existing imaging techniques on the Harwell campus;
- Develop new software that will enable imaging techniques to be combined and facilitate the use of advanced techniques by new users;
- Connect with other Technology Gateway Centres in mutually beneficial areas including the Detector Systems Centre and high performance computing research at Hartree Centre;
- Establish integrated/interoperable data handling, dynamics and data accessibility needed for storage, analysis comparison and display by provision of crucial computer hardware and software with sophisticated data analysis and storage technology;
- Enable correlative imaging at different scales through the use of different imaging modalities that cover a wide range of length, time, sample size and scattering regimes (e.g. light and electron microscopies, laboratory and synchrotron x-ray facilities, neutron facilities);
- Develop imaging sciences in the following areas: life sciences (e.g. imaging 3-D live cell cultures), biomedicine (e.g. disease progression research contributing to new therapeutic approaches [linking with appropriate partners for disease model development]), environment (e.g. heavy metal contamination), materials (e.g. magnetic structures and nanoparticles studies to achieve true atomic resolution in three dimensions), engineering (e.g. 3-D stress fields and composition);

- Enable leveraging of funding and the long term sustainability of UK imaging sciences;
- Provide training on advanced imaging techniques to both Industry and Universities.
- Increase the competitiveness of UK imaging sciences compared to technology intensive research institutions overseas [MIT, EMBL, Harvard max Planck etc] by developing consortia of imaging scientists and technologists who will be drawn in via access to centralised ISC activities capability;

Call for Partnership

It is envisaged that visitors (both long and short-term) will make up the majority of those working within the centre. The ISC will therefore operate in a manner analogous to the nearby Research Complex – with which it will have close ties.

The business model of the ISC envisages that the Large Facilities Capital Fund will provide the capital necessary to complete the building and the nucleus of the new equipment needed by the centre. It further plans that STFC will provide the resources necessary to maintain this equipment, both through external maintenance contracts, and the provision of imaging scientists, technicians & software engineers who will support users in their use of the equipment. In this way the ISC instruments will be made available to the UK research community in the same way as ISIS or Diamond beam-lines.

However, the full scientific mission of the new centre will require active, resident scientific teams to exploit the new imaging capabilities - both within the ISC and on Diamond, ISIS and the new Research Complex.

Some potential teams have already been identified (from Imperial College, Oxford, Manchester and UCL) and these will be used as exemplars within the Business case to be put to BIS.

Following approval of the ISC there will be a public 'call for Participation' in which the STFC seek research teams that would like to make a commitment to becoming a partner of the ISC. This call will be open to all UK researchers, and will be followed by a peer reviewed procedure to select the partners that will actually be accommodated within the ISC.

Table 1: Proposed new ISC Instrumentation

A	EM for Life Scientists	Cryo- EM with 300kV FEG for both single particle analysis and cryo electron tomography. This will be a state-of-the-art instrument with the latest fast-readout electronic detectors which is capable of sustained remote operation without manual intervention. By combining remote operation with advanced closely-coupled computing (likely using arrays of GPUs) it will be possible to provide an efficient user service and to shorten the time to final tomogram calculation or 3D reconstruction. This will also act as a driver for the improved integration of appropriate software, as has been achieved in X-ray crystallography by the combined impact of CCP4 and high throughput synchrotrons. Overall this facility will provide cutting-edge performance and a high level of user support, to enhance the productivity of the UK structural biology community. Applications to include molecular and cellular structures, encompassing single particle docking and fold recognition in computational biology, to cell biology, with 3d structures of organelles and cells.
B	Environmental TEM for Physical scientists	A unique (scanning) transmission electron microscope capable of world leading high resolution imaging and spectroscopy designed and optimised for in-situ experimentation under a range of atmospheres. The instrument will be an E(S)TEM operating at 80- 300 keV with <0.2eV energy resolution, 70pm spatial resolution and fitted with a high stability (1%/10hrs) FEG. This will enable high resolution spectroscopy and imaging and coherent diffraction experiments. Spherical aberration for both TEM & STEM to 5th order will be fitted. It will also include an Environmental Cell providing high temperature and controlled gas atmospheres. It is planned that the design will make possible the exchange of samples between the instrument and a range of beamlines to exploit synergies between synchrotron imaging and diffraction and state-of-the-art electron microscopy.
C	Super resolution Optical microscopy	Super-resolution and multidimensional single molecule imaging. This proposal will combine super-resolution and single molecule hybrid technology. It will pave the way to simultaneously accessing information on stoichiometry and conformation and its correlation with the dynamic and kinetic information from fluorescence microscopy. Additionally, special sample handling stages and techniques will be put in place to enable correlative microscopy between not only the different Octopus microscopy stations, but also electron microscopes, and x-ray microscopes on the Diamond Light Source.

D	High specification scan probe microscope	High field/low temperature ultra-high vacuum (UHV) microscope in unique, low vibration and acoustic noise environment (provided by semirural site and unavailable at UK universities) for high resolution single atom imaging and spectroscopy of novel materials for energy, security and environmental care, complementary to real space optical and EM techniques elsewhere in the ISC and k-space tools at ISIS and Diamond, including not only diffraction and inelastic spectroscopies, but also angle-resolved photoemission, with which it will share UHV hardware (e.g. sample mounts). In addition to materials science opportunities associated with samples to be measured, the facility will nucleate on-campus technological competence and innovation in UHV sample preparation/ characterization, piezoelectric nanoactuators and more routine scan probes which form an increasingly important part of instruments on X-ray/UV beamlines.
E	Imaging Software	Relevant commercial software will be purchased, and new software developed to ensure the full exploitation of the new ISC facility. In particular software will be developed to enable the interoperability of the range of imaging modalities available on the Harwell Science and Innovation Campus.
F	Support equipment (Lab X-ray tomography, scanning probe microscopy, ..)	The aim will be to provide support equipment that will facilitate access to the ISC imaging equipment, and imaging instruments on STFC's facilities (ISIS, Diamond, CLF).

Table 2: Existing (and planned) instruments on ISIS, Diamond & the CLF

G	ISIS ENGIN-X	ENGIN-X uses spatially resolved neutron diffraction (500µm – 5mm) to non-destructively image stress and strain in engineering components and materials. The high penetrating power of neutrons allows imaging at depths up to several cm for samples up to 1 tonne. Stress rigs, also operating at high and low temperatures, are provided to enable imaging under a variety of conditions.
H	ISIS - IMAT	IMAT, operational in 2012, will be a unique instrument combining thermal neutron tomography and diffraction imaging. Exploiting the particular capability of pulsed neutron sources, it will utilise 'Bragg edge'

		imaging to enable contrast between different elements, but also between different crystallographic phases. It will also enable stress or texture imaging, though at lower resolution than Engin-X. As with other neutron techniques, imaging can be carried out non-destructively at depths of up to several cm.
I	ISIS – INES/VESUVIO	Neutron Resonance Capture Imaging is a novel technique which uses the characteristic gamma rays emitted following fast neutron absorption to enable element sensitive non-destructive imaging deep within objects, for example archaeological artefacts. The current resolution is about 1mm. In particular cases it is a valuable complement where more conventional X-ray or neutron radiography/tomography cannot provide sufficient contrast or penetration.
J	ISIS - OFFSPEC	OFFSPEC is a unique neutron reflectometer which combines conventional specular and off-specular reflectivity with neutron spin-echo techniques to enable three-dimensional atomic resolution studies of thin films. This will provide particular synergy with the ISC TEM.
K	CLF - Octopus	Octopus is a large-scale imaging facility, consisting of a central core of multiple lasers, linked to a number of independent or hybridised microscopy stations including, for example, single molecule TIRF microscopes and multicolour and multiphoton confocal microscopes.
L	Diamond I06	**The Nanoscience beamline I06**, uses an electron microscope to image and energy resolve photoemitted electrons. Operating since 2007 in the energy range 0.08-1.5 keV, I06 has a resolution of 50nm for clean flat surfaces in a UHV environment. The prime area of application is in supported magnetic nanostructures, nanoparticles. Study of organic systems is exceedingly challenging (due to radiation damage at such high photon fluxes).
M	Diamond I18	**The Microfocus X-ray Spectroscopy beamline I18,** operational since 2007, has 2-4μm resolution, with scanning X-ray fluorescence (XRF), absorption spectroscopy (XAS) and diffraction (XRD). Sub-micron stability and reproducibility permits analysis of local atomic structure in small grains and regions of inhomogeneous matter. The beamline has, as expected, attracted considerable interest from a wide scientific community working in many disciplines. Applications to date include biomedical (Alzheimers and hip implants) heritage, environmental (heavy metal contamination) geological, space (cometary) sciences, materials

		and corrosion science.
N	Diamond B22	**The Infra Red SpectroMicroscopy beamline B22**, operational in 2009, will offer the highest level of signal to noise attainable (> 2000) at a diffraction-limited spatial resolution (~λ/NA) on a IR microscopy by a broadband source. Thanks to the large front end of the beamline, the spectral range of work for microspectroscopy studies will cover both the mid-IR (2 to 25 μm), and the far-IR (calculations down to 500 μm wavelength). The beamline unique optical design allows for both the bending and edge SR source to be used either simultaneously on two separate end stations, or collected into one for IR imaging and/or photon consuming IR experiments. The experimental systems are Fourier Transform IR Interferometers under vacuum, coupled with Cassgrain optics purged Microscopes equipped with broadband mid-IR MCT detectors, far-IR Bolometer and a Focal Plane Array for imaging in the near- and mid-IR region. The typical scientific cases span from sub-cellular IR microscopy ex vivo for medical research (e.g. cancer diagnosis and treatment), to mapping for material science (e.g. composite materials and polymer interfaces), solid state physics (e.g. quantum dots) or surface science (catalysis and electrochemistry), geomineralogy and high pressure studies (mineralogy), as well as Archeological and Cultural Heritage applications (parchments, dyes and lacquerer, potteries).
O	Diamond I12	**JEEP** will be operational in 2009 and will operate in either white or monochromatic mode at energies of 50- 150 keV, essential for imaging thick samples. JEEP will offer facilities for diffraction and radiographical imaging at resolutions of 5µ or better in two hutches. The first hutch will enable high intensity diffraction measurements in real time of geological and engineering components under controlled environments such as uniaxial loading. Fast (< 10 secs) tomographic images and very rapid (< 10 msecs) radiographic monitoring will be used to map the stress gradients around cracks in engineering components. The outer hutch will provide a large beam of 20 × 100 mm for a range of in-situ experiments to be undertaken. These will include ground-breaking experiments to simulate service conditions experienced by real engineering components and dynamic real-time measurements of flow processes in micro-pilot plants transferred from chemical process laboratories. The use of tomography for the study of palaeontology is a rapidly growing area of SR which will be served by I12.

P	Diamond I13	**I13L,** operational in 2011, is a ~220m long beamline that will exploit the high brilliance of undulator beams at Diamond for **Imaging and Coherence** related methods. The spatial resolution is on the micro- and nano-length scale, operating in the energy range of 6-30 keV. The coherence branch uses x-ray diffraction techniques in which 3-D images of nanoscale structures are obtained by recombining the diffracted (speckle) patterns. The resolution for this so-called *lensless imaging* mode is expected to be 20-50 nm. The imaging branch will carry out phase contrast imaging and micro-tomography over a large field of view and with high photon flux. For nano-resolution (100nm) X-ray optics will be used. Applications include imaging cochlea structure in the ear, dynamic imaging of dendritic growth, astro- and geophysics internal strain in nanostructured materials and nanostructure in biomaterials.
Q	Diamond I08	**The Scanning X-ray Transmission Microscopy (STXM)** beamline forms part of the diamond Phase III stage which has been recently approved by RCUK. It will use radiation in the energy range 250 to 3000 eV, with image resolution down to ~20 nm. The central theme of the beamline is the ability to obtain morphological and chemically-specific information on a full range of materials (inorganic/organic) under real (wet, 'dirty') conditions, providing a facility that will be new to the UK. Relatively thick (~10 – 20 µm) samples can be studied with both absorption and phase contrast techniques. The STXM will have the capability to produce high quality spectroscopic (NEXAFS) data for chemically-sensitive analysis, and x-ray fluorescence (XRF) mapping when operating at the upper end of the photon energy range.
R	Diamond CTXM	The full field cryo-transmission microscopy beamline (**CTXM**) will be dedicated to the study of biological samples with a particular emphasis on the imaging of cells. The scientific case for this Phase 3 beamline has been approved. The beamline will operate in the water window (284-543eV) where differential absorption between carbon and oxygen will provide the contrast. It will also extend to higher energies (2.5keV) for phase contrast work at greater depth of focus. The technical specification of the beamline will be driven by biological applications however applications from the wider scientific community will be welcomed. This project has particular interest in the correlation of data between the different imaging modalities (EM and the various forms of LM) anticipating that this will be a significant user requirement, It is expected that the beamline will be able to handle pathogenic samples.

S	Diamond I14	**The Hard X-ray Nanoprobe beamline** is proposed to form part of Phase III. It will deliver radiation in the energy range, 3 – 25 keV with the aim of better than 30 nm resolution. The optical design will be optimised for scanning X-ray fluorescence, X-ray spectroscopy and diffraction. Measurements will be made in the presence of electric and magnetic fields, and in different environments at controlled temperatures and pressures.