Neutron Radiography Applications in Industry, Agriculture, Archaeology and Art

1. Industrial

- *Inspection of mission critical components such as ordnance used to fire different devices in space launchers.*
  CT imaging could be used for these small-size devices, possibly ~ 100 mm in diameter.

- *Inspection of firing mechanisms of pilot ejector seats in fighter aircraft.*
  CT imaging would be suitable for these devices that are normally < 200 mm in length.

- *Detection of blockage in cooling channels of aero-engine turbine blades cast using the lost wax process.*
  Single exposure radiography with good contrast should be adequate for turbine blade inspection, with long exposure times.

- *Inspection of new reactor fuel elements and control rods for voids, cracks, incorrect fuel enrichment, burnable poison distribution etc.*
  For multi-plate fuel elements, it would be necessary to use CT over sections of the fuel element bundle to build up the data for the whole element.

- *Visualisation of two-phase flow phenomena in fluids such as water, organic refrigerant and liquid sodium (e.g. in heat exchangers and in refrigeration equipment).*
  This would require the setting up of a dedicated test loop facility in front of the neutron imaging system. For this application, a high speed camera (i.e. 30 frames/second or more) with intensification or high gain would need to be used so that short duration exposures are obtained that would freeze turbulence effects and bubble flow and allow for analysis of the flow regime.

- *Detection of boron in welds.*
  This would normally be in specimens that are fairly planar so that a single long exposure giving high contrast should be adequate for this inspection.

- *Visualisation of multi-phase flows in food manufacturing.*
  This would also require the setting up of a customised test loop with representative flow conditions and would need a high speed camera whose imaging rate and shutter speed match the flow parameters and requirements.

- *Identification of lubricating oil and coolant flows or leakages in operating machinery and engines or in components (e.g. vacuum pumps, automobile engines and gearboxes).*
  In the operation of rotary machinery, it would be possible to use a strobing technique to image only for a very short period of time during each motor/engine rotation and then integrate this image data for a large number of rotations, with the camera gated by a trigger pulse taken from the machine drive shaft. The delay time of this trigger pulse could be varied to obtain images at different points in the machine's cycle. Sections of engines, such as the cylinder block, cylinder head, gearbox cover etc may also be radiographed separately to investigate the presence of any cracks into which oil may have seeped and become trapped.

- *Visualisation of water and oil diffusion through porous media such as concrete and soil core samples.*
  These are fairly slow processes so that it would be possible to set up the camera system on a slow acquisition cycle – perhaps every 10 – 30 minutes. Alternatively, if some

asymmetry is expected in the diffusion process, CT scans repeated at regular intervals may be required.

- *Inspection of pre-stressed concrete to detect the presence of water around the steel reinforcement rods.*
  For large test pieces, it may be necessary to carry out only a few radiographic exposures at different orientations. High contrast in the images would be desirable.

- *Testing of the function of water protection agents used to protect building materials.*
  If the test pieces are small and irregular, CT scans might be necessary to observe the extent to which water penetrated the materials.

- *Imaging of retained water leaking into honeycomb panels used in the aircraft industry (e.g. helicopter blades).*
  These are generally planar objects so that CT would not be possible. There are several techniques used for identifying the presence of fluids like water inside test sections. If the imaging system can be operated at video rates (25/30 frames/second), shaking of the test object will result in movement of the fluid in large cavities and this may be observed in video sequences. Alternatively, if the test object can be turned upside down, any fluid would shift and this would be observed in the second image taken. A third technique used has been to image the region of interest and then apply heat to that region for a sufficiently long period, using hot air dryers, following which another image would be taken to see if the water had dried as a result of the heat treatment.

- *Identification of regions of corrosion and of adhesive material in aircraft components.*
  The test pieces normally used might be large panels that would need to be set up in front of the imaging housing. Exposure times should be long in order to obtain high contrast images that could be analysed to discriminate between corrosion and the presence of adhesive materials.

- *Visualisation of fuel flows through carburettor/fuel injector in automobile engines.*
  For any operating fuel injector, it would be necessary to set up a small test stand with pump and fuel supplies in front of the imaging system. If this were to be installed on a rotating turntable it would be possible to obtain a set of CT images of the injector in steady state operation.

- *Investigation of Lithium battery storage capability and performance.*
  The battery could be set up for off- or on-load evaluation using CT. High resolution images would be required and these would require long exposure times.

- *Examination of interfaces between molten salts or binary metals.*
  This type of test would require setting up a custom test loop on which full safety analysis would have been performed. The choice of camera and exposure parameters will depend on the properties of interest in these materials.

- *Investigating the behaviour of heat pipes.*
  These will be of relatively narrow diameter so that high spatial resolution will be required. Relatively few angular orientations of the test objects will normally be necessary.

- *Imaging of neutron poison materials in graphite.*
  CT would be possible on these test pieces if their geometry is not very asymmetric. Long exposures may be necessary in order to enhance contrast if the poison concentration is low.

- *Inspection of O-rings, rubber joints or diaphragms used in high pressure containers.*

It may be necessary to carry out CT in some of these applications, particularly in the case of complex geometry of the container housing the organic compound joint material.

- *Detection of porosity in moulded cavities using water or gadolinium nitrate solution as a contrast enhancement.*
  If the moulded cavity does not have strong neutron absorption properties, it should be possible to carry out CT to detect porosity.

- *Visualisation of gel injected into sealing compartments of equipment designed for underwater use.*
  CT would be ideal for determining the complete volume structure occupied by the gel.

- *Studies of the uptake and drying out of wood materials.*
  These test samples would probably be of a range of sizes but within the size defined by the thermal neutron beam, CT of these materials, using long exposure times, would be the preferred technique.

- *Identification of gas-liquid interfaces in high pressure containers.*
  In the large test structures that might be necessary for this type of investigation, it would probably not be possible to manoeuvre the test section once this has been set up so that it might be more useful to carry out direct radiography with a high speed imaging camera in order to view the dynamics of the processes involved.

- *Determination of dimensional changes or movements in components undergoing strain or other type of testing in a high pressure environment.*
  The type of radiographic imaging to be carried out will depend on the geometry of the test piece and the shape and dimensions of the high pressure container. If this test piece is a flat section, direct radiography would be suitable. For samples having a complex shape that could distort volumetrically as well as move during the test, CT would be recommended.

- *Studies of hydride storage capability in metallic alloys.*
  For a hydrogen storage material in a plate type of geometry, it may be possible to obtain the required information with a single radiographic image. However, if there are a number of these plates in a stack, CT would be necessary to determine the complete spatial distribution. CT could also be used to determine the variation of hydrogen storage distribution with time from when storage is begun.

- *Measurement of the boron doping of silicon wafers.*
  These are planar devices so that only direct radiography would be necessary, with long exposure times being used to obtain high contrast.

- *Inspection of porosity and density variation in SiC and other advanced ceramics.*
  For three dimensional test samples, high resolution CT scans would be necessary.

- *Investigation of bubble movement and void fractions in fluidised beds.*
  Fluidised bed test sections would have to be set up in front of the imaging system. Because of the considerable height of many of these fluidised bed reactor installations, the support frame should be capable of lifting the test section up to image it over its complete height.

- *Study of water distribution and transport in polymer electrolyte fuel cells.*
  Single plate fuel cells can be easily radiographed in one single exposure. For small arrays or stacks of planar fuel cells connected up to their gas supplies that can be mounted on a rotating turntable, these may be inspected by CT. The water distribution in the cell can, therefore, be determined as a function of time and cell operating power level.

- *Phase contrast imaging of fibre-reinforced and other materials.*
  This is an important technique that has been developed for different modes of imaging, including neutron radiography and synchrotron radiation imaging. It provides more information on the structure of an object by including refractive effects as well as the direct attenuation effects observed in a typical radiographic image. This is an area with the potential for use by many new applications.

- *Studies of geological samples.*
  Any size or shape of sample is likely to be investigated. High resolution imaging would be required as much of the information required is probably at the crystallite level. High resolution CT could be applied to any of these test pieces.

2. Agriculture

- *Study of the growth of roots, shoots, leaves and flowers and the movement of water in small plants.*
  High resolution radiographic imaging with long exposure times would be the most suitable for most of these applications.

3. Archaeology & Art

- *Investigation of archaeological finds particularly those with much corrosion or organic materials present externally or internally.*
  Direct radiography and CT would be applicable for all types of test objects with long exposure times recommended to achieve the highest image contrast.

- *Neutron activation auto-radiography of paintings or illuminated manuscripts.*
  There are slightly different ways of carrying out this technique but the most common is to irradiate the object and activate different materials in the paints or inks used. Gamma rays emitted by the activated elements would be detected by a sensitive area detector. This procedure could be used firstly with the neutron-sensitive scintillation screen in place to obtain a direct neutron transmission radiograph. Following this, the screen would be replaced with a gamma-sensitive one to obtain the gamma-produced image. These two images would then be inter-compared to help identify the artists' materials and their distribution.