Institution: University of Surrey

Unit of Assessment: UOA 9 Physics

Title of case study:

Next-Generation Airport Baggage Scanners Revolutionising Passenger Security Checks

1. Summary of the impact (indicative maximum 100 words)

Radiation physicists at the University of Surrey developed a unique X-ray imaging technology for high-speed real-time tomography (RTT) during 1997 to 2005. The originating research developed new X-ray methods for tomographic imaging of multiphase flow in pipes. RTT was then applied to security X-ray imaging, specifically the high-speed screening of aircraft passenger baggage. As a direct result of the research, a spin-out company from the University, CXR Ltd, was formed, and it was later acquired by Rapiscan Systems.

Surrey's imaging technology is now approved for use for automated explosives detection in the European aviation sector. In 2009, a prototype high-speed baggage system was trialled at Manchester Airport, which resulted in certification in 2012. The research has made a significant economic impact by leading to technology that created jobs in a purpose-built factory.

2. Underpinning research (indicative maximum 500 words)

The research was carried out within the Radiation and Medical Physics Group at Surrey between 1997 and 2005. The research idea originated from an initial discussion with BP Exploration about multiphase flow metering of well heads. Dr Ed Morton proposed the idea of real-time tomography for this application. BP were interested in such a development and provided seed funding to start a research programme.

The research team investigated a wide range of components including electron guns, X-ray anodes, vacuum systems, high voltage insulators, X-ray detectors and data acquisition systems. The components were developed to the proof-of-concept stage. Specifically, they demonstrated an end-to-end imaging system, going from an electron gun to the image on a screen, using components that were all designed from first principles for this task (ref. 1). These component developments include:

- Design and modelling of a multi-emitter grid-controlled electron gun and associated electronic drive circuits. Key issues to solve were inter-emitter uniformity and low grid switching voltage. Morton's team adopted a space charge-limited design approach using tungsten filaments with closely spaced grid elements to minimise switching voltages. This work has evolved over the intervening period to high-performance, high-reliability, low-cost designs with excellent uniformity and low switching voltages.
- Design and integration of a high speed multi-channel X-ray detector and data acquisition system. This was based on scintillation detectors with photodiode readout. A range of other detector technologies were investigated, with some significant work being completed on gas microstructure detectors and room temperature semiconductor detectors. Several publications on room temperature semiconductors and gas microstructure detectors resulted from this related work.
- Design and modelling of X-ray targets (ref. 2). At the time of this programme, the physics in standard Monte Carlo radiation transport codes was poorly implemented, if at all. The team developed an accurate low energy expansion of the EGS4 code framework, which was well received and proved valuable in designing anodes and the optimal imaging system (ref. 3).
- Design and testing of an image reconstruction algorithm for non-coplanar transmission tomographic imaging. This was based on the Feldkamp approximate 3D algorithm. In related

work, this algorithm was applied to BBSRC funded programmes on high resolution 3D X-ray micro-tomography.

In parallel with the instrumentation development, modelling of multi-phase flow was conducted in collaboration with Prof. Tuzun in the Department of Chemical Engineering. The tomography programme was driven by Morton (a senior lecturer in physics) with a team of two post-doctoral researchers (Luggar and DeAntonis) and four research students (Kundu, Key, Tavora, Menezes).

3. References to the research (indicative maximum of six references)

(1) E.J. Morton, R.D. Luggar, M.J. Key, A. Kundu, L.M.N. Tavora, W.B. Gilboy, "Development of a high speed X-ray tomography system for multiphase flow imaging" *IEEE Trans Nucl Sci* 46/3 (1999) 380-384.

This paper describes a new system for quantitative measurement of multiphase flow, which makes use of high speed (50 frames per second) X-ray tomographic imaging.

(2) L.M.N. Tavora, E.J. Morton, F.P. Santos, T.H.V.T. Dias, "Simulation of X-ray tubes for imaging applications" *IEEE Trans Nucl Sci* 47/4 (2000) 1493-1498.

The cross-section for the electron impact ionisation of the K-shell for selected materials, and given by different sources, is analysed. The results obtained for silver and molybdenum targets in transmission and reflection geometries, and for different tube voltages, are benchmarked against experimental data. When appropriate models are in use, simulated and experimental spectra agree within 15% at the K-alpha peak.

(3) L.M.N. Tavora, E.J. Morton, W.B. Gilboy, "Design consideration for transmission X-ray tubes operated at diagnostic energies"*J. Physics D* 33/19 (2000) 2497-2507.

A low-energy expansion of the EGS4 Monte Carlo code system was used in studies that aimed to understand photon production in transmission target X-ray tubes. The characteristics of X-ray spectra measured along the beam path were determined for targets of different materials, thicknesses and beam energies. The relation between efficiency and the fluorescence-to-bremsstrahlung ratio is shown.

Primary Funding for Research

(1) E.J. Morton (1997-1999) £198,000 from BP Exploration: "Measurement of water cut using high speed X-ray tomography"

(2) E.J. Morton, U. Tuzun, W. Gilboy (1999-2002) £350,000 from the EPSRC Instrumentation Development Grant (GR/M50300/01)"Quantitative multiphase flow metering using X-ray tomographic imaging"

(3) U. Tuzun, E.J. Morton, and P.M. Jenneson (2001-05) £330,916 from EPSRC (GR/R34370/01) "Novel Interfacing of Computer-Aided Imaging Techniques to Probe Microscopic Evolution of Nano-Powder Assemblies"

4. Details of the impact (indicative maximum 750 words)

The primary impact of Surrey's research is economic through the creation of a viable spin-out company, new jobs, and new commercial products. Impact from the research started in 2001, and it continued throughout the REF period.

Soon after the terrorist attacks in the USA on September 11, 2001, Morton met with leading experts in security inspection. This meeting inspired the creation of a spin-out company, called CXR Ltd, in the summer of 2002. Morton was the founding director and CEO, and three members of the university research team (Luggar, DeAntonis, Menezes) were employed there. This job creation marked the first example of economic impact. The work conducted at the University and subsequently at CXR Ltd. led to the filing of over 20 patent families on all aspects of the design and application of RTT systems [Corroboration C1]. In 2004, after three rounds of investment, OSI Systems Inc, a global privately-held company, embedded CXR's technology in its security division company, called Rapiscan Systems, which is based in the UK.

According to an OSI Systems report in 2005, the company had the vision that RTT "if successfully completed, could provide significant improvements over current hold baggage screening technologies." [C2] Today, the primary application of RTT technology is in the security inspection business, specifically for high-throughput automated screening of hold baggage for improvised explosive devices.

Since the formation of the spin-out company, many $M have been invested in the technology. In early 2009 two types of high-speed baggage systems, with tunnel diameters of 80 cm and 110 cm, were trialled at Manchester Airport in a $7M contract (making additional economic impact).[C3] The key objectives of the trials were to establish reliability of the system with real passenger bags, to collect data for certification, and to benchmark the system integration efficiency. Certification was obtained for the 80 and 110 cm systems in 2012 and 2013, respectively, approving them for use as standard three-hold baggage screening systems with automated explosives detection. Following the trials, the first two fully-operational systems will be installed at Manchester Airport as part of a contract worth in excess of $20 million.

Scanning airport baggage for explosives and other suspicious items is usually a time-consuming task. First, bags go through an automated X-ray system and, if this shows something suspicious, the bag is put into an automated hospital-style X-ray computerised tomography (CT) scanner, which is used to build up a cross-sectional image. However, CT scanning is slow, and the initial X-ray scan often throws up false positives. Surrey's research developed a system that can produce CT images in the same time as a single automated X-ray system. RTT cuts out one step of the scanning process, it reduces the cost of scanning, and it also reduces false positives [ref. C4, C5]. When applied to hold baggage, RTT scanners can scan 1200 to 1800 bags per hour, which is four times faster than current technologies, which is beneficial to the aviation industry and to airport passengers. Rapiscan's RTT 80 System offers significant cost savings in comparison to standard CT scanning [C6]: up to 50% on maintenance; 33% on infrastructure (installation and integration); 23% lower hardware costs (fewer machines required because of faster scanning); and 30% on lifetime recurring costs.

The technology arising from Surrey's research has led to job creation and new industrial products. More than 50 engineers are employed on Rapiscan's RTT programme at a new UK factory in Salfords, Surrey that was specifically built for the manufacture of the key technology in the RTT system: the multi-emitter X-ray tube. Thus, the technology and principles behind RTT are together creating economic impact through a major export-led business, based in the UK, with US financial backing.[C7]

There is other continuing economic impact in job creation and exports. A broad technology platform for high energy X-ray inspection of cargo systems, developed by Morton, is manufactured in the UK from a purpose-built factory (65,000 sq. ft.) near Stoke-on-Trent. This factory currently employs over 60 staff in both engineering and operations. From here, $M high energy inspection systems are exported to all parts of the world. Parts of these systems use the core detection and electronics technologies that were initially developed with University expertise at CXR.

EPSRC has recognised the Surrey research as having a high impact. Specifically, they highlighted the Surrey research in their 2011 Annual Report as an example of "high quality and high impact projects funded through investigator-initiated research base funding." [C8] The significance of the RTT technology behind the Rapiscan Systems products was recognised by an award from *The Engineer* magazine in the category of Defence and Security and by the Best Innovator Award (2011/12) from the Airport Operators Association. [C9]

Rapiscan Systems and CXR Ltd. have made significant efforts to engage with the wider research community. Active research programmes are in place with the University of Surrey as well as with STFC staff at Harwell and Daresbury. There is on-going research on RTT reconstruction algorithms. The methods so developed are now being written in real-time implementations for use in the main RTT systems.

EU European Civil Aviation Conference "Standard 3" requirements for explosive detection systems stipulate that after 2014 all new baggage systems must use CT scanners and by 2018 all old, non-CT systems must be replaced. With the RTT scanner that emerged from Surrey research, Rapiscan Systems is therefore well placed to become the major supplier of CT scanners to airports in Europe and the rest of the world.

5. Sources to corroborate the impact (indicative maximum of 10 references)

(C1) List of patents: http://www.patentmaps.com/inventor/Morton_Edward_James_1.html

(C2) 2005 OSI (Rapiscan) US NASDAQ 10k Report

(C3) Contract with Manchester Airport Group: http://www.airport-int.com/article/rapiscan-systems-solid-state-ct-systems-high-speed-hold-baggage-screening.html

(C4) Information on Real-Time Tomography on the Rapiscan Systems website and on YouTube: "Rapiscan Real Time Tomography: A Breakthrough Technical Innovation in Aviation Baggage Screening"

http://www.rapiscansystems.com/technologies/real_time_tomography

"Hold Baggage Screening"

http://www.rapiscansystems.com/en/products/hbs

(C5) Video about Rapiscan RTT - Real Time Tomography for Better Checked Baggage Screening http://www.youtube.com/watch?v=p-I5ABn0T7M

(C6) http://www.rapiscansystems.com/en/products/hbs/rapiscan_rtt_80

(C7) Group Chief Technology Officer, Rapiscan Systems, Torrance, California, USA. Contact details provided.

(C8) *Engineering and Physical Sciences Research Council Annual Report and Accounts*, printed on 24 November 2011. Available on-line at:

http://www.official-documents.gov.uk/document/hc1012/hc16/1614/1614.pdf

(C9) Article related to the award from *The Engineer*:

http://www.theengineer.co.uk/awards/defence-and-security/1005774.article; Best Innovator Award: http://www.rapiscansystems.com/en/press_releases/article/rapiscan_systems_awarded_best_innovator_at_the_airport_operators_associatio

(C10) Airport Business press release: http://www.airport-business.com/2010/10/xrd-3500-achieves-ecac-standard-3/