Scope

INSTITUTE OF PHYSICS AND ENGINEERING IN MEDICINE | www.ipem.ac.uk | Volume 25 Issue 2 | JUNE 2016

P27 APPLIED ACADEMICS
The permanent member of staff, from lecturer through to professor

P30 MEDICAL PHYSICS
Dose to water or dose to medium? Reporting absorbed dose

P39 CLINICAL ENGINEERING
Managing and reducing medical device alarms in a clinical setting

Spotlight on educational practice in teaching

Soldiers without arms
Limb prostheses in WWI

MRI safety
Join us...

...at the forthcoming Bayer Educational Symposium. At the Crossroads of Patient Radiation Protection.

Due to impending changes in EU radiation protection legislation, which will impact on how UK hospitals monitor their delivered doses of ionizing radiation, Radiology departments need to start planning now for how they will potentially manage these new requirements.

This exciting and informative event will look at the need to record and report every patient’s radiation exposure. In addition to looking at the new directive the event will highlight practical case studies of data capture from the UK and Switzerland.

We hope you can join us for this major event.

**Date:**
Wednesday 6th July 2016

**Time:**
11.30 - 16.45

**Location:**
Whiston Hospital, Prescot

**Will be of interest to:**
- RPAs
- Medical Physicist
- CT Radiologists
- Interventionalists
- Cardiologists
- Radiology Business Managers
- CT Superintendents

As places are limited, reserve your place online by registering for the Bayer Symposium at: bayersymposium.ya-yaonline.co.uk

**CPD Accreditation** Application Applied For

Approved by BIR

[CPD Now Certification Logo]
**CONTENTS**

**THIS ISSUE**

**FEATURES**

10 Magnetic resonance imaging safety
Hazards in magnetic resonance imaging from the effects of the strong static magnetic field

13 Spotlight on best educational practice in teaching
Aspects of educational theory and good practice in the teaching of physics and engineering applied to medicine

16 The Chartered Engineer
The benefits of professional registration and how to go about achieving Chartered Engineer status through IPEM

18 Equality, diversity, inclusion
A commitment from IPEM, following the appointment of its first Trustee Lead for Equality, Diversity and Inclusion

20 The case for software testing
Bugs have feelings too! The importance of software testing and how to achieve a good balance when doing so

24 Biomedical engineering associations in Africa
A new initiative workshop held for professional healthcare-related associations of sub-Saharan countries

**APPLIED ACADEMICS**

27 Academic careers: permanent member of staff

**MEDICAL PHYSICS**

30 Dose to water or dose to medium?
32 In vivo application of prompt gamma range system

**CLINICAL & BIOMEDICAL ENGINEERING**

35 The role of the clinical engineer in device management
37 The history of non-invasive blood pressure monitors
39 Managing medical device alarms in a clinical setting

**HISTORICAL FEATURES**

50 Cover feature: Soldiers without arms
Francis Duck

56 Fascinating life of Ronald Woolmer, the founder of BES
Hilary Dunlop and Shirley Coleman

**REGULARS**

04 Trustee update Engaging and integrating
05 IPEM National Office update Work of the finance team
06 Editor’s comment Editor-in-Chief Engaging you!
08 Policy update Members’ involvement in influencing policy
26 Members’ letters Correspondence from readers on all topics
41 Special reports An overview of recent online meeting reports
42 Reviews Latest books, reviews, reports and newsletters
47 Member profile Hannah Dryer and Shelley Taylor
49 Obituary Michael R. Neuman
Traditionally, one of the Scope editorials has been written by the President. As part of a new initiative, and in line with IPEM’s strategy to spread the workload of the President, editorials will in future also be given by various Trustees who hold key positions within IPEM. The first of this new series will be written by myself as President Elect.

What is IPEM?
The first and most obvious issue is: ‘what is IPEM’? Traditionally, IPEM has been the home for NHS medical physics and medical engineering with a dominant patient focus. The work of IPEM follows the charitable aims, which are ‘to promote for the public benefit the advancement of physics and engineering applied to medicine and biology and to advance public education in the field’. It is interesting to note that the words ‘NHS’ and ‘patient’ are missing from these objectives. Four phrases appear from these objectives. ‘Medical physics’ and ‘medical engineering’ are familiar. However, there are also ‘biological engineering’ or ‘bioengineering’, and ‘biological physics’ or ‘biophysics’. The extension of IPEM activities to bioengineering, following integration with the Bioengineering Society (BES) in 2015, might be thought of as being a new venture for IPEM. However, the founding fathers of IPEM clearly had in mind at its inception that IPEM should be more than just NHS medical physics and medical engineering, as the words ‘bioengineering’ and ‘biophysics’ are implicit within IPEM’s charitable aims. These discussions of identity will be paramount in the current strategy review which will set objectives for the work of IPEM for the next 3 years, and in current discussions on the structure of IPEM. In parallel will be the intention that IPEM continues to act as the professional body for NHS medical physics and medical engineering, but also that IPEM is able to develop for the future in other areas which have always been part of IPEM’s charitable objectives.

The President Elect has traditionally been an ‘in-limbo’ post, mainly concerned with training to be President. Whilst the ‘in-training’ bit is still true it has been recognised that the role of the President is too large, and the 2 days a week which this has taken in the past are difficult to justify to an employer. Hence, efforts are being made within IPEM to spread the load of the President. This has meant that my time so far as President Elect has not been in-limbo as the involvement in eight IPEM committees testifies. In particular, I have been involved in continuing the work on engagement of IPEM with the academic community.

Plans are underway to fully integrate BES members and activities into IPEM. Currently, the BES holds its annual scientific meetings jointly with the Wellcome Trust and EPSRC-funded Medical Engineering Centres (MEIs). The BES–MEI annual meeting is in Oxford in 2016, a few days before MPEC. The 2016 MPEC format will be different to previous years and involve a 1-day free event involving prize giving, professional matters etc., followed by 2 days of science. This 2016 meeting will be a halfway-house towards full integration in 2017 with the BES, when the first IPEM–MEI meeting will be held in London.

Working together in the future
During Stephen Keevil’s time as President, discussions were started on how the three main institutes concerned with physics and engineering in medicine and biology might work together. These discussions between IPEM, IET and IMechE continue, and we hope to announce in due course a series of joint events.

A series of three articles on the academic career has been written, jointly with Stephen Keevil, for IPEM Scope magazine. These are being extended into a book on academic issues which will be available later in 2016 and hopefully be of interest to new and aspiring IPEM members.

In summary, I see the next 2–3 years as being key to the future of IPEM in terms of its continued support in its traditional area of NHS medical physics and engineering as well as its engagement of the other communities relevant to ‘physics and engineering applied to medicine and biology’.
Kathryn Surtees (Head of Operations and Finance) gives an overview of the responsibilities of the finance team at the National Office.

The work of the finance team at the National Office incorporates everything financial. In this article, I am going to give members an overview of the team and the vital work they do for members and IPEM.

The finance team consists of me, the Head of Operations and Finance (HOOF), Nicola Parkinson, Finance Officer, and Sandra Wilkinson, part-time Finance Assistant; with additional help from Emma Corden, Office Administrator.

As HOOF I am responsible for the financial and risk management of the Institute, including preparation of budgets and forecasts, the application and monitoring of financial control procedures, and advising the CEO and trustees on key strategic decisions.

I am also responsible for compliance with all legal requirements for the charity, including data protection, health and safety, company and charity administration, HR and the IT infrastructure.

The activities provided by the finance department cover a wide range, from basic book-keeping to providing information to assist trustees and managers in making strategic decisions.

At the base level, the finance department is responsible for all the day-to-day transactional accounting for the charity, including paying member expenses and supplier invoices, collecting membership fees and other income, and paying staff. We prepare monthly management accounts so that the CEO and trustees can monitor the operations and decide where further attention may be required. We also produce VAT and corporation tax returns, and prepare the financial statements for external audit.

Each member of the team takes on specific roles

The Finance Officer is responsible for the preparation of the management accounts, including making adjustments for accruals, prepayments, sundry debtors, sundry creditors and depreciation, as well as being responsible for all aspects of banking and banking reconciliations, payroll, stock control, systems administration and overall control of the balance sheet.

The part-time Finance Assistant is responsible for credit control, coding and checking member expenses and supplier invoices, processing payment runs and ensuring our Direct Debit mandates are updated in accordance with the Direct Debit Guarantee.

The Office Administrator is responsible for processing expense claims and supplier invoices, processing publications, chasing expense claims and purchase orders and processing payments.

At a more tactical level the finance department is responsible for the management of the charity’s cash flow and ensuring there are enough funds available to meet the day-to-day payments. Where there are cash needs beyond the day-to-day working capital, the finance department is responsible for advising and sourcing longer term financing.

Looking to the future

Where there is excess cash beyond that needed for the day-to-day running of the charity, the finance department is responsible for advising and sourcing investments via an investment manager.

Looking forward, the finance department works with the CEO and trustees, and uses historical data to prepare the charity’s budgets and forecasts, and to report on the progress against these throughout the course of the year.

Finally, the finance department is called upon to provide information to assist the CEO and trustees in making key strategic decisions, such as which markets or projects to pursue in order to achieve IPEM’s charitable objective to advance physics and engineering applied to medicine.

In recent years, the finance team has been instrumental in bringing members:

- online payments;
- online access to electronic journals;
- increased interest from IPEM’s cash reserves, and
- faster reimbursement of expenses through acceptance of scanned receipts.

In summary, the finance department should be considered a resource to assist the CEO and trustees in the running of the charity, and in improving the efficiency of the organisation for members’ benefit.
One of Scope’s strategy aims is to engage its readers using various means, and it is always a pleasure to find that our efforts are bearing fruit! In this issue we have a couple of response letters from Professors Stanley Salmons and Tony Denman. At the same time, you will notice a few changes in content, in line with our strategy recommendations. These changes include:

- Special themes – covering an area in medical physics or clinical or biomedical engineering. These provide members with an insight into various aspects, e.g. clinical practice, research, development, training and management.
- Editorials – we now have revised titles: ‘Trustee update’ (formerly ‘President’s update’) and ‘IPEM National Office update’ (formerly ‘CEO’s column’). This will allow our members to have a broader understanding of the work of IPEM trustees and staff.
- Sections – any feature that relates to medical physics or clinical and biomedical engineering will appear under the respective area.
- Letters – inclusion of correspondence from members on any feature that appears in Scope.

Inevitably, board membership terms come to an end and this has meant that David Stange and Professor Malcolm Sperrin have decided to step down as Clinical Technology and Applied Academics Editors, respectively. Dave, with his extensive treatment planning experience, supplied a number of quantity features for his section. I’ve had some very helpful discussions with Malcolm over the last few years. On behalf of our editorial board and readers, I would like to thank them both for their contributions to Scope and wish them well in their future endeavours.

In this issue, we have our very first ‘special theme’ on the management of medical devices. Dr Michael Ayers has worked hard to bring us three enticing features, one of which is on the management of alarms in neonatal intensive care units – an experience I can’t forget! Need I say more?

With the advent of MR imaging systems attached to linear accelerators, MR safety has been one of the focal points in recent conferences. Andrew Fry, Haris Shuaib and Sarah McElroy have supplied us with a neat two-part series on MR safety. This first part covers safety in static magnetic fields, touching on hazards, quenching, implants and occupational exposure.

Late last year, I invited Dr Jamie Harle to provide a pedagogical article based on the academic part of our clinical training. This would partly help me in delivering clinical oncology lectures as part of the MSc at the University of Birmingham. Co-authored with Dr Liz Parvin, we have an excellent three-part series on best educational practice in medical physics and biomedical engineering. In this first installment, they explore aspects of educational theory and good practice in the teaching of physics and engineering applied to medicine. For those teaching undergraduate or postgraduate courses, this is a must!

You will also find the third and final series article on academic careers by Professors Peter Hoskin and Stephen Keefil covering the full-time academic, from lecturer to professor. We hope you have enjoyed reading the series as much as I have. If you have any comments, please let us have them in the form of a letter, email or a Tweet.

Have a good read and a fantastic summer!
Every discussion of progress in healthcare involves harnessing data. Still most organizations only use a fraction of the data available to them.

Elekta Knowledge Management solution turns your clinical and business data into meaningful insights. With real-time visibility and analytics, your data becomes the prescription you need to facilitate personalized treatment. Accelerate clinical discoveries and raise practice quality and performance across the entire continuum of care.

Visit elekta.com/healthcareanalytics

Please contact info.europe@elekta.com for more information.

Improving patient lives through Information-guided care™
IPEM’s officers and committee members work hard on behalf of the Institute trying to influence policy at all levels, around the UK and in the wider world, to achieve IPEM’s strategic objectives. Some of their efforts are listed below, but for a fuller picture keep an eye on the policy pages of the website, under Policy and External Affairs.

**Updates**
The submission date for the consultation on British Standard 70000 for Medical Physics, Clinical Engineering and Physiological Science Services in Healthcare – Requirements for Quality, Safety and Competence was extended to March 2016, so IPEM’s response to this was still being compiled when this article was submitted. See the IPEM website for the final response.

IPEM’s response to the Northern Ireland Department of Health, Social Services and Public Safety’s consultation on the Public Health Act, put together by the Radiation Protection Special Interest Group (SIG) in collaboration with the Regional Chair for Northern Ireland, was extensively quoted in the consultation round-up document. We hope to be able to influence the next stage of the revision of the Act, which aims to enable governments and public authorities to respond effectively to incidents and emergencies involving infectious diseases, and chemical and radiological contamination.

**Consultation responses**
Various IPEM committees and SIGs were busy in the first quarter of 2016, responding to:

- The NHS consultation on a unified policy on whistleblowing (Professional and Standards Council).
- A consultation on Fulfilling our Potential: Teaching Excellence, Social Mobility and Student Choice (compiled by Jamie Harle, Secretary of the Academic Advisory Group on behalf of several committees).
- The Health Select Committee’s request for evidence on the impact of the Comprehensive Spending Review (compiled by Jemimah Eve, Workforce Intelligence Manager from the National Office, commenting on the impact on the medical physics and clinical engineering workforce numbers).
- Chief Professional Officers’ Medicines Scoping Project (compiled with responses from a number of SIGs giving views on the potential need to extend the right to prescribe, supply or administer medicines to healthcare scientists).
- In February, the Nuclear Medicine SIG commented on the decision by Monitor and NHS England to drop HRG4+, and the Vice President Engineering, the Clinical Engineering SIG and others provided written evidence to the Commons Select Committee inquiry on the EU regulation of the life sciences (see above).
- In March, the Radiotherapy SIG prepared a response to a consultation about the future of Clinical Reference Groups – part of the specialist services commissioning infrastructure in England. Also, the Informatics and Clinical Computing SIG was involved in the consultation on standards for the Informatics Higher Specialist Scientific Training.

All of the consultation responses, and other policy activity that IPEM undertakes, can be found on the Policy pages of the website, so that members can see what has been submitted. Where a round-up of consultation responses, including IPEM’s, has been published, we post this on the website too, so that members have the full picture.

IPEM is a member of the Campaign for Science and Engineering (CASE), which provides regular policy updates and opportunities to attend policy events, including talks and debates. CASE updates are also posted on the Policy and External Affairs pages. If members are interested in attending any policy events, they should get in touch with our External Relations Manager, Sean Edmunds, by emailing sean@ipem.ac.uk.
need that degree... for your next promotion?

FdSc Hospital Engineering or FdSc Medical Equipment Technologies
BSc (Hons) Management of Healthcare Engineering Technologies & Facilities

Continue working and study part-time to achieve a relevant Foundation Degree, leading to a BSc (Hons) Degree awarded by Staffordshire University, subject to approval. For further information visit our website.

e-mail training@eastwoodpark.co.uk | call +44 (0)1454 262777

eastwoodparktraining.co.uk

For more information www.msc-neuroimaging.com
msc-neuroimaging@kcl.ac.uk

MSc in Neuroimaging

Join a one year Master programme at King’s College London’s Institute of Psychiatry, Psychology and Neuroscience (IoPPN), one of the world’s largest post-graduate teaching and research centres for studying the brain in health and illness.

• King’s College London’s Neuroimaging department has pioneered work in functional MRI, diffusion tensor imaging, pharmacological MRI, EEG and advanced physics of image analysis techniques.
• From imaging physics, studying rare patient populations and running scanning sessions to analysing and interpreting data, this MSc provides comprehensive training in the science and methodology of neuroimaging techniques and their application to neuroscience, psychology, psychiatry, neurology and beyond.
• All lectures are given by experts in their field providing students with in-depth knowledge across the spectrum of neuroimaging specialisms.
• The course is aimed at applicants with a good first degree from a wide variety of backgrounds including, mathematics, physics, engineering, computer science, biomedical sciences, neuroscience, and psychology

www.msc-neuroimaging.com
msc-neuroimaging@kcl.ac.uk

IPEM SCOPE | JUNE 2016 | 09
The hazards associated with magnetic resonance imaging (MRI) may seem obvious to anyone working regularly in an MR department. However, to the uninitiated (new staff members, patients, maintenance and research personnel and students, for example) the dangers may not be so readily apparent. MRI enjoys a reputation as a ‘safe’ imaging modality due to its lack of ionising radiation. Of course, this is a major advantage of MRI but it is important that the very different, but very real hazards of this modality are fully appreciated by anyone involved in its use.

The hazards of MRI can be categorised under three main headings:
- the static magnetic field;
- time-varying (gradient) magnetic fields, and
- radiofrequency (RF) pulses.

In the first part of this two-part article on MR safety, we shall consider the static magnetic field. The gradient magnetic fields and RF pulses will be discussed in the second part, in the next edition of Scope.

**Static magnetic field**

The main hazard of an MRI scanner is the presence of a strong static magnetic field. For clinical systems, the magnetic field strength is typically 1.5 or 3.0 tesla (T). This is roughly 300 or 600 times stronger than the magnet in a refrigerator door seal! Introducing any ferromagnetic object into this field will result in a potentially deadly projectile as the object is drawn towards the magnet bore at high speed.

**Projectile hazards**

The potential for a distracted member of staff or a forgetful patient to enter the scanning room with a magnetic object in their pocket is a persistent concern for MR departments. Of the many projectile incidents reported, one example in 2009 vividly demonstrates the importance of MR safety. In this incident, a patient attendant entered the MR environment with scissors in their pocket. The scissors were pulled out of their pocket and embedded themselves in the MR technician’s forehead, requiring surgical removal.¹

The first, and so far only, death due to a projectile in MRI occurred in 2001. In this infamous case, an oxygen cylinder was taken into the magnet room by a nurse, untrained in MR safety, in response to shouts for help from an anaesthetist. The tank was ripped from the hands of the anaesthetist and entered the bore, striking the 6-year-old patient on the head. A root cause analysis...
identified numerous faults which led to this unfortunate incident, including lack of MR safety training and unrestricted access to the MRI suite.3

The most significant physical control to ensure MR safety is the use of MR CONTROLLED ACCESS AREA (CAA). These areas have access controls, such as self-locking doors and warning signs placed at each entrance.3

Free access is granted only to MR authorised personnel, such as radiographers, MR physicists and radiologists. Within the MR controlled access area is the MR environment, typically demarcated as the scanner room, which contains the magnetic field of 0.5 mT and above.3 Below this field strength there is considered to be no hazard due to the magnetic field.3

Any object which may be brought into the MR environment should be clearly labelled using internationally recognised labels such as ‘MR Safe’ or ‘MR Conditional’ and, for the latter, the conditions (figure 1).1 Ferromagnetic items that could mistakenly be moved into the MR environment, such as chairs, should clearly be labelled as ‘MR Unsafe’.3

Screening of patients and staff entering the MR environment is a fundamental part of MR safety. Unauthorised persons should be verbally screened by an MR authorised member of staff before entering the controlled access area, and a written questionnaire must be completed before entering the MR environment. Where screening has been absent or inadequate, there have been a number of reported incidents and anecdotal accounts of near misses.5,6

The latest high-profile MR incident occurred in Mumbai in November 2014, when a ward assistant brought a large oxygen cylinder into the MR environment, pinning the ward assistant and a technician to the scanner.7 In emergency situations such as this, a ‘quench’ can be initiated; the magnetic field is quickly destroyed by heating a small part of the normally superconducting magnet, causing resistive heating and subsequent venting of the evaporated helium gas. This can result in damage to the superconducting niobium-titanium joints and it is very expensive (at least £25,000) to refill the system with helium. Clearly, accidental quenches are to be avoided but the ability to perform an emergency quench is vital. This point was unfortunately demonstrated in the Mumbai case; the quench button was apparently disabled and the two victims remained trapped against the scanner for 4 hours. This resulted in serious injuries to the two men caused by prolonged pressure and the loss of circulation, as well as the initial force of the impact.7

Quench
A quench pipe routes the venting cryogen out into the open air. During a quench, the pipe becomes a pressure vessel and therefore requires reasonably complex design.6 This is usually done by the manufacturer but it is worth noting that after installation, in most cases, the quench pipe becomes the responsibility of the hospital’s own estates department, who are to ensure that regular checks occur. If the pipe fails or is blocked, the scan room could fill with helium gas, displacing the oxygen and potentially leading to the asphyxiation of any occupants. For this reason, oxygen monitors are fitted in the scan room. There is also the risk of cold burns from the very cold cryogen.

Implants
The static magnetic field exerts an attractive force on any ferromagnetic implants present in a patient’s body. Most orthopaedic implants or fixation devices are non-ferromagnetic and anchored to bone, so there is little concern that these devices may move due to interaction with the magnetic field. Some implantable devices require a 6–8 week wait before scanning for fibrosis to occur, securely holding the implant in place when subjected to the scanner’s magnetic field. For implants in the brain, such as aneurysm clips, fibrosis does not usually occur. Non-ferromagnetic clips may be safely scanned, but the clip identification must be 100 per cent certain before proceeding. There has been a reported fatality where an aneurysm clip was incorrectly identified as being non-ferromagnetic.7

For many metallic foreign bodies, the main safety concern is not the force exerted on the device by the magnetic field, as is often assumed, but rather the potential for heating to occur due to RF exposure (discussed in the second part of this article). Historically, pacemakers have been an absolute contraindication for MRI. Modern devices, however, are now available that are MR Conditional, allowing patients to be scanned under certain conditions.10 Before scanning these devices, an MR safety expert (MRSE) should be consulted and the scan must be performed in strict accordance with the manufacturer’s guidance.

Biological hazards
The main interaction of the static magnetic field with the human body is the induction of currents when moving through the field. Moving quickly through the field (> 1 Ts-1) can induce vertigo and feelings of nausea. These effects are transient and can usually be avoided by moving patients slowly.

---

**FIGURE 1.**
Internationally recognised labels (ASTM International Standard F2503) should be clearly visible on all pieces of equipment which may be taken into the MR environment.
into the magnet bore. There is no evidence that exposure to static magnetic fields causes any serious or long-term health effects, although there is as yet relatively little data, particularly for fields of strength greater than 8 T.1

**Occupational exposure to static magnetic fields**

In 2013, the European Commission published Directive 2013/35/EU, setting out the minimum health and safety requirements for workers’ exposure to electromagnetic fields (EMF).3 The Health and Safety Executive recently ended their public consultation on the proposed Control of Electromagnetic Fields at Work Regulations 2016, which will translate the EU directive into UK law. The draft regulations contain a derogation allowing workers to exceed the EMF exposure limit in relation to use of MRI equipment for medical purposes (including research and other related activities).4 Due to this derogation it is thought that the implementation of these Regulations will not be unduly onerous for MRI departments.

**Conclusion**

The presence of a large static magnetic field presents a number of challenges and hazards unique, in the hospital, to MRI. The continued safety of staff and patients relies on the strict exclusion of MR unsafe objects and implants from the MR environment. This requires excellent training and awareness of the hazards in order to minimise the risks. A magnetic resonance safety expert (MRSE) who is ideally a qualified clinical scientist should be available to every MRI department to provide advice on MR safety.3

**REFERENCES**

1 FDA. MAUDE Adverse Event Report 3003768277-2009-00050; received 17th July 2009. http://1.usa.gov/1qtQZRg


5 FDA. MAUDE Adverse Event Report 4643240; received 22nd October 2009. http://1.usa.gov/1oBqfwS

6 FDA. MAUDE Adverse Event Report MW5013870; received 20th March 2015. http://1.usa.gov/1PTvzSr


Spotlight on best educational practice in higher education: part one

Jamie Harle$^{1,3}$ and Liz Parvin$^{2,3}$ discuss aspects of pedagogy related to the teaching of physics and engineering applied to medicine. This article outlines the current educational landscape for such taught programmes within UK higher education institutes (HEIs), making clear the differences in learning attainment between the various levels of educational qualification awarded by HEIs. In doing so, this article aims to answer the convention of why academic entry requirements for many forms of professional membership (e.g. MIPEM, chartered status, state registration) are set at masters level and why the skills developed in science or engineering degrees at postgraduate level remain in demand by many employers.

Subsequent parts of this series will develop these concepts further to discuss contemporary teaching practice within the UK, outlining examples of good practice and summarising likely trends in future educational delivery and assessment. These are increasingly influenced by evidence-based educational literature, requirements for professional training, patterns of student recruitment (including for overseas students) and the availability of new educational technologies in the teaching environment. Another factor is funding mechanisms for higher education, which dictate the resources allocated to deliver good teaching and improve the learning environment.

Higher education reforms

This series is published at a timely stage in the UK government’s proposed higher education reforms and hopes, in future parts, to offer parallel commentary and insight, on implications of policy changes for university teaching. Such changes were first outlined in July 2015 by the Minister for Universities and Science, Jo Johnson, to create ‘sharper focus’ on teaching activities within the HEI sector through four targeted themes:

- Improved social mobility and widening participation
- A simplified single student-centric administrative architecture
- Opening up of the sector to providers outside established universities
- The introduction of a Teaching Excellence Framework (TEF) to measure institutional teaching quality and incentivise its improvement

As a parallel activity to this higher education policy, there is also a review examining the governance of university research funding and the workings of the long-established Research Excellence Framework (REF). REF has markedly changed the mechanisms of reward and career progression in university research activity since its introduction; it was instigated in the late 1980s as a tentative audit exercise for monitoring research spending, but has evolved into an expanded metric-based administrative behemoth that definitively scores...
best educational practice

**SOLO TAXONOMY**

<table>
<thead>
<tr>
<th>Competence level</th>
<th>Complexity level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unistructural</td>
<td>State</td>
</tr>
<tr>
<td>Multistructural</td>
<td>Repeat</td>
</tr>
<tr>
<td>Relational</td>
<td>Define</td>
</tr>
<tr>
<td>Extended abstract</td>
<td>Identify</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Describe</td>
<td>List</td>
</tr>
<tr>
<td>Explain</td>
<td>Perform Task</td>
</tr>
<tr>
<td>Design</td>
<td>Outline</td>
</tr>
<tr>
<td>Create</td>
<td>Compare/contrast</td>
</tr>
<tr>
<td>Hypothesise</td>
<td>Appraise</td>
</tr>
</tbody>
</table>

**FIGURE 1.** Using SOLO taxonomy to characterise levels of complexity in student learning. The verbs outline some tasks that are typically attributed to each level of cognitive thought.

The higher educational landscape

Despite a wide range of discipline names, the education field has remained firmly split into two distinct professional groupings, with engineering degree titles (i.e. BEng) and a distinct science degree focus (i.e. BSc). There are relatively few UK programmes that attempt to merge science and engineering disciplines; this may be a consequence of the structure of the engineering and scientific professional bodies as well as the faculty organisation of most UK universities. It is, however, a slight quirk in the modern world given that the job roles of many Scope readers involves some interdisciplinary working with team roles that straddle across the full ‘greyscale’ coverage between engineering ‘black’ and scientist ‘white’.

According to the UK Universities and Colleges Admissions Service (UCAS), physics undergraduate degrees are currently delivered by around 50 HEIs, often as a BSc qualification over 3 full-time years, or an MSci/MPhys award if extended to a fourth year, but with variations in title to cover a wider initial field of study, such as natural sciences. Over 10 UK programmes offer a formal medical physics route in the final year(s) to enable a ‘Physics with Medical Physics’ degree title specialism, or similar. Accreditation of such programmes for quality assurance purposes has been traditionally performed by the Institute of Physics. In engineering, there are currently over 20 biomedical-themed undergraduate degrees, often badged as a BEng over 3 years, or an MEng if extended to 4. A larger number of courses can be identified if the search net is cast wider using terminology such as ‘mechanical and medical engineering’ or ‘materials engineering’, where the wet-lab disciplines of engineering, such as biomaterials and tissue engineering, are included as well traditional dry-lab applications involving computing, electronics, mechanics or technology.

A growing trend in UK engineering undergraduate programmes has been for a large amount of the teaching to be alongside or integrated with students from other engineering disciplines. This promotes multidisciplinary learning across generic engineering themes like design skills, problem solving and data analysis as well as specialism-specific topics, which for biomedical engineering may include anatomy and physiology, medical device regulation or the interaction of radiation with tissue.

These programmes are often accredited by the Engineering Council through a joint assessment framework involving several professional bodies.

Undergraduate degrees are also delivered at a small number of UK universities as the educational component of healthcare technologist training, for example ‘BSc Healthcare Science’ with specialisms such as cardiac physiology, nuclear medicine or radiotherapy physics. An alternative to a full degree over 3 years has been instead to re-skill existing graduates, or those with equivalent experience and education, through a shorter conversion course that studies the equivalent to the final year of an undergraduate degree, building on existing prior learning to reach the equivalent standard at graduation. This qualification is called a Graduate Diploma (GradDip), and has proven successful in other professions where many entrants are mature students bringing existing relevant workplace experience. IPEM is in the process of developing an accreditation framework to monitor the quality and curriculum of such technologist-orientated qualifications.

In the UK, MSc degrees are normally taught full-time over one year. This differs from the practice in many parts of continental Europe where the required total study hours are considerably higher than can be achieved in 12 months. There are around a dozen UK universities delivering a postgraduate in medical physics programme with a lower, but growing, complement in fields of biomedical engineering. IPEM runs an accreditation framework for masters level programmes, which was launched in 2014 and now has coverage across the majority of medical physics MSc courses in the UK, as well as respectable coverage among the UK’s biomedical engineering masters programmes.
Levels of higher education

A postgraduate degree differs from an undergraduate degree not only in its requirements for prior student learning, known as its prerequisites, but also in the learning outcomes which the student must demonstrate from studying the programme to reach the qualification award. In brief, masters level is predominantly achieved by teaching to Framework for Higher Education Qualifications (FHEQ) level 7, as defined by the UK Quality Assurance Agency for Higher Education (QAA). Undergraduate programmes teach over FHEQ levels 4–6. Level 7 requires students to demonstrate more than just knowledge of the underlying concepts and principles of their subject and an ability to evaluate and interpret data in their work, which progressively satisfy FHEQ levels 4–6. At FHEQ level 7, students are also expected to demonstrate critical thinking in their work. This is a much misunderstood concept due to the mistaken ‘negative judgement’ connotation of the word ‘critical’.

Critical thinking is expanded upon in figure 1 through the taxonomy model of Biggs and Collis, known as the structure of observed learning outcomes (SOLO). Here, SOLO taxonomy is presented as four levels of learning achievement (a fifth level, defining incompentence, is omitted). They show increasing complexity in student thinking and resultant demonstration of higher competence in a subject area. Each level is associated with a different approach to the synthesis of learned concepts and the linking together of prior knowledge.

Unistructural problems are those that exploit simple and obvious connections, such as recall knowledge of facts or the use of simple mathematical relationships. Multistructural problems are those which demand the formation of a number of connections between different learned concepts, but in which overall meta-connections between concepts are missed, as is their significance for the whole. X-ray imaging, for example relating the radiation dose from an imaging protocol to its stochastic risk of cancer or its implication for image quality, meets this level of understanding, but there remains an inability to propose an overall optimal imaging solution that exploits understanding of multiple concepts governing imaging unit performance. Here, a student can only really support the activities of a more senior colleague who possesses the interrelational understanding to complete the optimisation process; the student can’t act independently or take control of a real-world scenario without such all-round knowledge.

Critical thinking

Relational problems are those where the student can now appreciate the significance of different concepts and variables that influence the overall workings of a multiparameter system, and correctly explore potential solutions, each with pros and cons, and compromises and assumptions. At this level, students can contribute constructively to workplace or practical scenarios featuring imperfect conditions or imprecise information. As a result, the student is now becoming relatively employable and can ‘add value’ and advancement through his/her individual input as well as being able to work independently with suitable experience and training. Consequently, this forms the baseline cognitive level required to practise competently in many professions.

At extended abstract thinking, the student is now solving problems by designing, generalising or hypothesising, and generating considerable original thinking through extending his/her previous learning to a new scenario. Success at working sustainably to this level of cognitive thought often forms the basis of successful doctoral work (FHEQ level 8), if it can be defended robustly and shown to be original and contributory to scientific literature. Whilst the four levels of cognitive thought do not directly relate to each outlined FHEQ level, one should expect more complex cognitive processes to be achieved for higher qualification levels. Lower levels of complexity form the developmental process for undergraduate studies, whilst the masters level is based solidly around success with relational problems, involving comparison, discussion and analysis of learned concepts, rather than its knowledge recall. There might also be some extended abstract thinking in project work. Thus, the masters level develops cognitive ability similar to those required for professional recognition.

The next article will explore examples of good practice from HEIs as identified from IPEM accreditation activities. Figure 2 outlines examples of such teaching practices that will be discussed, and orders them according to their passive or active nature, and the resultant complexity of student thinking that can be normally achieved. From this diagram, it is apparent that a student’s approach to learning can be influenced by the delivery format of teaching sessions, with a number of modern teaching methods, such as problem-based learning (PBL), offering advantages by naturally enabling more interactive learning with opportunities for students to form more complex relationships between concepts, however there are disadvantages introduced. This matter will be explored further in the next article.

![Forms of Experiential Learning](https://example.com/figure2.png)

**Forms of Experiential Learning visualised through Dale’s Cone of Experience concept**

- **Passive learning**
  - Lectures
- **Active learning**
  - Tutorials or Project work
  - Problem-based learning (PBL) or Group projects
  - Teaching others
- **Private study**

---

www.ipem.ac.uk
The Chartered Engineer

Deborah Seddon explains the benefits of professional registration and how to go about achieving Chartered Engineer status through IPEM

How do I become registered as a Chartered Engineer?

Professional registration is an important milestone for an engineer and technician. It demonstrates that you have met the high standards of competence and commitment set by the engineering profession. Registration also shows your peers, employers and society that you are committed to professional standards and to maintaining and enhancing your competence through continuing professional development (CPD). In short, it sets you apart from those who are not registered.

The standards for the engineering profession are set, maintained and published by the Engineering Council, the UK regulatory body for the engineering profession. The key document to refer to if you are interested in becoming a Chartered Engineer (CEng) is the UK Standard for Professional Engineering Competence (UK-SPEC).

UK-SPEC sets out the standards that an individual must demonstrate if he/she is to be admitted to the Engineering Council’s Register of professionally qualified engineers and technicians. For each of the five headline standards of competence, there are subcategories and examples to assist you in identifying activities you might include, to demonstrate that you meet the CEng requirements. This is covered later in the article, along with an overview of the registration process and the role played by professional engineering institutions such as the Institute of Physics and Engineering in Medicine (IPEM).

Competence and commitment

In a fast-moving sector like engineering, it is important for the profession to ensure that its requirements for registration remain current and fit for purpose. The standards in UK-SPEC are reviewed every 5 years. The most recent review in 2013/14 found that there was a high degree of support amongst stakeholders for the standards, with only a few suggested areas for revision. Broadly, these were to strengthen areas that had come to the fore since the previous review, such as intellectual property (IP), security and risk. Therefore, you can be confident that in working towards CEng, you are working to standards that have a high degree of currency and credibility.

The new edition of UK-SPEC also includes definitions of competence and commitment, and this helps to explain the building blocks on the way to registration. Achieving competence requires the right level of knowledge, understanding and skill, as well as a professional attitude. Many of you will have followed a structured education programme such as a degree, followed by on-the-job training and experience, generally known as initial professional development (IPD). However, compared with some other professions, the engineering profession is more open and accessible and is not prescriptive about how you achieve competence. For CEng status, whilst there is a so-called ‘standard route’ to registration for those holding a degree accredited by the Engineering Council, it is also possible to become registered if you can demonstrate the required knowledge and understanding in other ways, via the ‘individually assessed’ route.

So what is a Chartered Engineer?

Chartered Engineers develop solutions to engineering problems using new or existing technologies. They apply their technical knowledge and use their innovation and creativity to solve engineering problems and develop new analytical techniques. They may be responsible for complex systems which involve a significant level of risk. Chartered Engineers should be able to demonstrate that they have been accountable for project, finance and personnel management, as well as managing trade-offs between technical and socioeconomic factors. People skills and communicating technical matters are also vital. So, also, is undertaking work in a demonstrably sustainable and ethical way.

If you think this sounds like you, then look up the five headline standards of competence. Those referred to as the A and B standards of competence focus on the...
technical engineering side of things, including general and specialist knowledge and applying theoretical and practical methods, and the C and D standards are concerned with technical and commercial leadership, management, responsibility, effective interpersonal skills and communication skills. The E standard is all about demonstrating your personal commitment to professional standards, the ethical and environmental obligations involved in being a professional engineer, as well as your commitment to CPD.

The A–E headline standards of competence are further described in UK-SPEC with exemplar activities, though these are not exhaustive. IPEM will also be able to advise you about activities specific to your sector that should enable you to demonstrate the requirements.

Which route to registration is for me?

There are broadly two routes to becoming professionally registered, the so-called ‘standard route’ for those holding an accredited degree listed on the Engineering Council’s database, and the ‘individually assessed’ route.

Holding an accredited MEng degree provides the full educational requirement for CEng status. You can check the status of your degree using the public searchable database, by intake year. A list of accredited degrees can be found on the Engineering Council website, [http://www.engc.org.uk/courses](http://www.engc.org.uk/courses). You can also work towards CEng registration if you hold an accredited BEng with honours by undertaking what is termed ‘further learning’ to Masters level. That could be an accredited MSc or other Masters degree, or an Engineering Doctorate. Another option is a work-based learning or experiential learning scheme.

An example is the flexible, work-based degree framework called Engineering Gateways, developed by the Engineering Council and offered by some universities, that integrates learning with the development of professional competence. More information is available by speaking to your Institution or visiting the website ([http://www.engc.org.uk/engineeringgateways](http://www.engc.org.uk/engineeringgateways)).

Don’t worry if you don’t hold an accredited degree. If you can demonstrate the same level of required knowledge and understanding in other ways, you can still achieve registered status. The best advice to give is to speak to an IPEM membership advisor for examples of how others have successfully completed the ‘individually assessed’ route.

The professional review process

IPEM is one of the 35 professional engineering institutions licensed by the Engineering Council to assess whether an individual member should be admitted to the Register. This means that the Engineering Council has confidence in IPEM to interpret the UK-SPEC standards for your sector and for the Institute to assess CEng applicants, a process known as professional review. The Engineering Council sets out the requirements for the professional review process which all institutions must meet, ensuring a level of consistency across the profession.

As part of your professional review, you will be required to submit documentary evidence to show how you meet the UK-SPEC standards as interpreted by IPEM. The evidence will include details of your educational record, structured or other professional development, areas of accountability and a plan for future professional development. Applicants may also have a mentor, an existing registrant, who can provide advice and support on their application.

You should speak to an IPEM membership advisor for specific details about the forms you need to complete and the evidence required. For anyone seeking CEng registration, there will also be an interview conducted by two trained and qualified peer assessors. They will determine whether, in their opinion, a candidate meets all of the requirements and make a recommendation to the relevant IPEM committee about whether they can be awarded the CEng title, or not.

An important part of the registration process is for you to take the time to reflect on how you have met the required competence and commitment in your working life and only to apply for registration once you are ready.

A word about commitment

Registered engineers and technicians make a commitment to the profession, to society and to the environment. They commit to:

- comply with codes of conduct, including the IPEM code;
- contribute to sustainable development in their engineering activities;
- manage and apply safe systems of work to safeguard society;
- carry out the necessary CPD to maintain and enhance competence, and
- actively participate within the profession.
Equality, diversity, inclusion: commitment from IPEM

Kimberley Saint has been appointed IPEM’s first EDI Trustee Lead and wants to show that diversity and innovation go hand in hand.

began my term as a Member Trustee of IPEM in Autumn 2014. The Board of Trustees is the governing body of IPEM and the Trustees are collectively and separately responsible for ensuring good governance. I and the rest of the Trustees are Company Directors of IPEM and registered with the Charities Commission as Trustees, as IPEM is a registered charity. I am very proud of this role and hope to do it justice over my 3-year term. Shorty after starting the role I was asked to be IPEM’s first Trustee Lead for Equality, Diversity and Inclusion (EDI). I accepted, hoping that as a trainee female clinical scientist working within the NHS and, I say this with respect, one of the younger members of the Board of Trustees, I could make a small difference. The first thing I wanted to do, as a scientist, was some research into EDI. However, my first question was: ‘why was this role developed?’ The answer was that IPEM have committed to initiatives with the Royal Academy of Engineering and the Science Council over the last few years, as well as wanting to take their own work further.

In October 2013, IPEM signed the Engineering Diversity Concordat. Led by the Royal Academy of Engineering, the Concordat is a voluntary commitment by professional engineering institutions that seeks to ensure that the profession properly reflects the society it serves, by attracting engineers from increasingly diverse backgrounds into the profession. The profession can then capitalise on their diversity of thought, innovation and creativity. In October 2014, IPEM was one of 16 Science Council member bodies that signed up to the Declaration on Diversity, Equality and Inclusion. In this, the Science Council and its member bodies publicly declared a
commitment to promote EDI throughout their communities and to challenge prejudice and discrimination. This will lead to greater opportunities for all individuals to fulfil their potential, irrespective of their background or circumstances. It will also help science to better serve society by attracting the widest possible talent to the science workforce. As part of this, IPEM committed to appoint a board-level diversity champion who, in partnership with a senior executive staff member/CEO, would be an advocate for the importance of EDI, and be accountable for this work.

Before doing any research I already knew from personal experience that, for example, there are fewer women studying physics at university than men. I was 1 per cent of the female contingent at my university. Recently, I was asked how I can be a Trustee of IPEM. It turned out that the individual thought I was too young. I took this as a compliment, given I am no longer in my twenties, and it has only spurred me on to try and make that small difference. However, I have been quite shocked, saddened and a few times appalled after reading various reports from the government, charities, professional bodies and from talking to colleagues, peers and others. Here are just a few facts that have stayed with me.

Findings from recent studies

- Analysis of those working across professional engineering shows that women make up 51 per cent of the UK population but only 8 per cent of the engineering workforce. With regards to ethnicity, whilst 26 per cent of UK resident graduate engineers are from black and minority ethnic backgrounds, they represent only 6 per cent of the engineering workforce.
- YouGov research of UK health and social care professionals revealed that in the last 5 years, 5 per cent of patient-facing staff have witnessed other colleagues discriminate against or provide a patient or service user with poorer treatment because they are lesbian, gay or bisexual. Some 26 per cent of lesbian, gay and bisexual staff say they have personally experienced bullying or poor treatment from colleagues in the last 5 years as a result of their sexual orientation, and 10 per cent of health and social care practitioners with direct responsibilities for patient care have witnessed staff in their workplace express the belief that someone can be ‘cured’ of being lesbian, gay or bisexual. This is despite the fact that the practice of conversion therapy has been condemned by NHS England and the British Medical Association.

I am proud to say that IPEM is committed to equality and inclusion principles and practices. IPEM is aware that EDI is not a box-ticking exercise in order to comply with legislation. A different set of experiences and perspectives can help IPEM flourish, as well as the workplaces of its members. Diversity and innovation go hand in hand.

The Trustees and IPEM staff have worked closely to develop an action plan over the last few years for EDI and are making steady progress in implementing these actions. We now have a webpage dedicated to EDI and are actively engaging with and supporting EDI events. I was recently invited to attend the opening of the new WISE offices in Leeds. WISE is a not-for-profit membership organisation working to promote women in science, technology and engineering. My take-home fact from this event was that women make up 14.4 per cent of those working in STEM occupations; 5 STEM being science, technology, engineering and medicine. IPEM members are fantastic at supporting outreach work, which I know will help redress this and other imbalances in our membership for the future.

The next action we wish to implement is the formation of networks to support members from all groups and to encourage volunteers to act as role models. I have personally spoken to IPEM members at various levels and the majority felt we are an inclusive body. However, this is not enough. IPEM’s diversity needs to be promoted. There are ‘invisible’ groups, like lesbian, gay, bisexual and transgender people and their supporters – often called LGBT+. If you only visited the IPEM website, read our newsletter or attended an event, you would not know that we have LGBT+ members.

If you would like to set up or join a network for any particular group of IPEM members, please let me know. If you would like to act as a role model please do contact us. Finally, if you have any comments you wish to pass on regarding EDI, IPEM are keen to hear them.

REFERENCES

6 Office for National Statistics. Labour force survey, August 2015.
The case for software testing: bugs have feelings too

Allan Green, Phil Cosgriff, Paul Ganney, Richard Trouncer and David Willis\textsuperscript{1} stress the importance of software testing in development.

They don’t like to be forgotten, they like to be understood, they have many friends to get to know… and they can bite if not appreciated.

Software testing is often described as a necessary evil, but it is entirely analogous with the commissioning and quality assurance that many IPEM members perform on a daily basis. Clinical scientists and engineers often spend more time testing their processes than developing them. Should more time therefore be spent testing the software than writing it? While no-one has ever regretted doing too much testing, software is often under tested. The aim of this article is to convince you of the importance of software testing and how to go about achieving a good balance.

Software development, and in particular the testing, should be considered to be akin to commissioning a new treatment technique or introducing clinical equipment. In both cases the aim is not to pass a test, but to find problems and then fix them. Only by finding problems and fixing them does quality improve.

The widespread move towards embedded controllers in complex devices (including, for example, motor vehicles) should only highlight the importance of systematic and comprehensive testing, especially in safety-critical systems. No system should fail because it was not suitably tested, and documentation should be available to show this.

(Yes, this includes spreadsheets.)

The false positive vs the small error

To a resource-starved manager, when they learn that software has been written and has not yet revealed any of its shortcomings, it is tempting for them to assume that it is ready to be immediately put into service. This must be resisted; the truth is that until we’ve conducted thorough tests we simply have no idea how bug-ridden a system is.
Errors that cause large, noticeable mistakes are easy to spot; however, it is often the small error that permeates through a system that causes the biggest harm to patients. In the past when major errors have occurred in the clinical environment, they can often be tracked down to a small factor that is somehow incorrect. As a positive outcome from these unfortunate incidents, reviews have been carried out, and we spend a good proportion of our time testing to eliminate such errors. We should learn from this for software as much as any clinical process.

How does testing fit into the process?
Testing is not the only necessary evil in software development. However, testing can remove a lot of the pain from the development process and many aspects of the process can complement each other. A model that is most often applied, explicitly or implicitly, is the ‘v-model’. The development is split into levels. The upper level (‘validation’) relates the broad-picture user requirements to the acceptance testing. The next level (‘verification’) is concerned with combining the individual components of the software, and testing this integration. The lowest level (also ‘verification’) is concerned with the performance of the smallest individual components of the software (a ‘unit’), each with a specification that it is tested against. At each level there is some form of specification which relates to a testing plan from which a testing report is produced. The detail within each level will depend very much on the project and though much of the legwork involved in this documentation is often duplicated, this process enables all aspects of the software implementation to be considered. Each level is tested in isolation and this saves considerable time.

The elephant in the room, and the hardest part of this process, is that all specification and testing plans need to be written before a single line of code is produced. This applies to so many aspects of what we do already, and as onerous as it sounds, a good specification and testing plan written in advance will save a lot of trouble down the line.

How do you test your software?
The first thing to note when considering the testing of the components of your software is that exhaustive testing is simply not possible. The number of variables present in any software prevents a brute-force testing approach. For example, a simple program that multiplies two numbers from 1 to 100 together has 10,000 outcomes and it is not practical or desirable to test each one. However, randomly poking at the software with a proverbial stick is equally unproductive. A number of aspects need to be considered when testing your software:

- the data used should exercise the software under a sufficient variety of circumstances;
- ideally, each statement within the code should be tested at least once;
- all branches of the software must be followed, and
- the boundary conditions of any data and calculations should be tested. This should include data beyond boundaries to see how the software responds.

Where possible consider automated testing. This involves taking a unit and inserting it into a testing frame, which takes a list of test data, runs it through the unit being tested and outputs the results. An example would be software designed to monitor a stream of data and provide a real-time calculation; the true performance of the software could not easily be tested without a testing frame. A further example would be using the record macro function to create a testing frame for a calculation within Excel. This has a number of advantages in that:

- it can run a large amount of varied data;
- it avoids human error in the process;
- it can be rerun with minimal fuss, and
- the output can form the body of the testing report described above.

The downside of automating your testing is that the testing frame itself is a piece of software and needs to be maintained separately.

If each unit has been tested to a high standard, the integration of these components can then be tested. Any errors found can then be attributed to how these units interact. This form of testing should include a number of test cases for which the input data reflects everyday expected use of the software. As the internal design of each component is not known, the data selected should cover the four points above but with a wider perspective than the intricate calculations within each unit.

Once the integration testing is complete then the acceptance can be carried out. This level of testing should cover the correctness of the system as a whole, resilience to improper use, general performance (for example in relation to CPU load and multi-user response), security and environmental factors such as hardware or operating system considerations.

At this point it is worth discussing who would be doing this testing. In an ideal world, an independent person would work on each part of the development process, providing a fresh specification-focused perspective. Practically, this is not always possible but efforts should be made to include people outside of the core group to provide this fresh approach. Testing does not require coding skills and it will help minimise any expectation bias – provided the testing plan is well laid out and accessible.

Bringing in people solely for testing...
without a proper specification and testing plan can result in a never-ending loop of bug fixing as the tester strives for absolute perfection. At release all software will still have bugs remaining in it – a fact that is sometimes all too apparent. Testing is not to remove all bugs; it is to ensure that they do not affect the performance of the software to an unacceptable level.

**Standards, regulations...**

It would be remiss not to mention ISO 29119 – the international standard on software testing. This standard aims to help define ‘best practice’ for software testing, and it will be hard to justify ignoring it. “However, the standard should never be hidden behind in place of good testing practices as testing, by nature, is driven by context.” (Google ‘Stop ISO 29119’ for arguments against using an ISO standard).

**Some notable examples**

**The Mars Climate Orbiter.** A very simple error was caused by two engineering teams using different units of thrust. Suitable integration testing was not carried out, resulting in the thrusters being 4.5 times more powerful than they should have been when approaching Mars. There is a new crater on Mars, costing $327.6 million.

**Patriot missiles.** These were designed to intercept Saddam Hussein’s Scud missiles during the first Gulf War. The trajectory calculations required very accurate timings. A subroutine for this was introduced but not referenced everywhere that it should have been. The error was detected but a work-around was introduced (reboot ‘every so often’) instead of a fix. One day it was off by 0.3 seconds, causing 28 deaths.

**And finally... Stanislaus Petrov.** On 23rd September 1983, at the height of the Cold War, the Soviet early warning system signalled that five nuclear missiles had been launched by the USA. Petrov’s role was to monitor the incoming data. Under significant pressure to signal a counter-attack, he judged that the system was in error and ordered his men to stand down. Later, it was revealed that the satellite system had detected the sun reflecting from the top of the clouds and the code designed to filter these signals out had failed. Nuclear holocaust was avoided because Petrov had ‘a funny feeling’.

---

_dolphin is an IBA Dosimetry GmbH product. OSL is the exclusive distributor in the UK & Ireland_
Physics in Medicine & Biology (PMB) celebrates its 60th anniversary in 2016. To mark this occasion, we invite you to attend a half-day symposium at Imperial College London held in conjunction with International Conference on the Use of Computers in Radiation Therapy (ICCR) 2016.

When: 30 June 2016, 9.00 a.m. – 12.00 p.m.
Where: Great Hall, Imperial College London

The symposium, which is part of the ICCR 2016 conference and features speakers drawn from the PMB editorial board, will include:

- talks on the history and future of medical physics
- broad perspective talks on the key advances and hot topics in both therapy and imaging physics, as well as the intersection of the two.

The symposium is free to attend but does not give access to the ICCR meeting.

Find out more and register now at [www.iccr2016.org](http://www.iccr2016.org)
Biomedical engineering associations in Africa

Anna Worm summarises a new initiative workshop held for professional healthcare-related associations of sub-Saharan countries

Professional associations representing the interests of their members have a long history of being able to raise professional standards and share learning and good practice. In healthcare, associations representing both clinical and other specialties are well established and are seen as an important part of the framework for professional development.

In sub-Saharan Africa, the development of healthcare-related associations has been piecemeal, but there is an increasingly visible acceleration in the creation of national and regional bodies which will perform some of the functions associated with professional associations in developed countries.

Tropical Health & Education Trust

In the case of biomedical engineering (BME) or clinical engineering (CE), some limited and unpublished research carried out by the Tropical Health & Education Trust (THET; http://www.THET.org) in January 2014 indicated that at least 14 of the 44 sub-Saharan mainland countries have a registered BME/CE professional association, but only two are national society members of the International Federation of Medical and Biological Engineering (IFMBE). During this research it became clear that many associations struggle with finances, what to offer members and other fundamental issues.

In October 2015, THET hosted a needs-assessment workshop for 16 sub-Saharan African BME/CE associations. The Clinical Engineering Association of South Africa (CEASA), a mature and successful association, participated as a facilitator. Fourteen of the 15 invited countries were present in Johannesburg (as shown in figure 1): Benin, Burkina Faso, Burundi, Cameroon, DRC, Ethiopia, the Gambia, Ghana, Ivory Coast, Kenya, Nigeria, Tanzania, Uganda and Zambia. The only country not able to attend was Rwanda.

Some interesting observations

Most of the associations are young and in the early phase of incorporation. They have gone through the
basic steps of setting up an association (a board, annual meetings, mission and vision, membership structures and fee structures) but struggle with financial management and sustainability, strategic planning, monitoring and evaluation, understanding member needs and member retention. The 16 associations together represent more than 3,000 biomedical engineering professionals.

The workshop has led to the initial formulation of potential projects
2. Sharing expertise (e.g. through webinars):
   a. financial management;
   b. action planning;
   c. website;
   d. monitoring and evaluation;
   e. continuous professional development;
   f. quality assurance for BME(T) training, and
   g. external relations.
3. Creation of an online platform.
4. Connecting to Northern bodies, like membership of AAMI, IFMBE or IPEM.

Execution of some of the projects depends directly on initiatives and interests from the Johannesburg group (in particular, 1 and 4). However, new and existing partners can initiate other projects such as sharing expertise through a webinar or creating a direct link with an individual or association. If IPEM members are interested in making a contribution through sharing their expertise or otherwise, please feel free to contact Anna Worm at THET using the details below.

Acknowledgements
The needs assessment workshop that took place in Johannesburg in October 2015 would not have been possible without the engagement of the sub-Saharan Africa BME associations and the financial support of the GE Foundation.

For more information please contact Anna Worm, BME consultant for THET, anna@worm.nl
More advice for PhD study

Dear Sir,

I read, with interest, Peter Hoskins and Stephen Keevil’s academic careers series article on ‘Studying for a successful PhD’, and would agree with many of the points made. I would add that, whilst a PhD student is well supported in a larger academic department, it is possible to follow a part-time PhD in a smaller NHS department, if you have strong support from your department and the local university, and have experienced supervisors. You will need strong motivation, and ability to work on your own – and have a clear assessment of, and commitment to, the extra work involved beyond your service responsibilities – even if your head of department is supportive. But you can propose your own project, convince your supervisors and the university, and see it through to a successful conclusion.

When considering a multidisciplinary PhD, one aspect the writers did not mention is the need for ethical approval for the clinical phase of the research. Whilst this phase often comes near the end of the research project, it is important to discuss at an early stage how the clinical phase will be done, in case the ethics of working with your chosen group, who may be children, prevents particular ways of evaluating the research. Another aspect, which is often a major challenge, is to recruit sufficient patient numbers in the study.

Publishing papers and giving conference presentations of your research is, as the authors mention, essential, not optional. It allows the presentation of bite-sized parts of the research in digestible chunks to enter the public domain – digital versions of the final PhD project may be available these days, but these tend to remain unread on the (digital) shelf. For a part-time student in a competitive field, it can be important to present aspects of the research as soon as possible, and prove that you thought of the idea first, rather than get to the viva and find that the external examiner has browsed ScienceDirect and found that someone published a few weeks ago. Comments at your presentation or on your paper can influence the later stages of your project; and the papers and presentations will look good on your CV. Publishing papers is not just about the department getting a good score at the next REF exercise.

I have to admit that I was frustrated, when Head of Department, that new physicists made no effort to publish their MSc projects. Don’t fall into this trap, especially if you might want to move from an NHS post to an academic career in the future!

Finally, there is also the possibility at some universities of gaining a PhD by published papers. Not all universities offer this route, and some restrict it only to their alumni, so you will need to do a little research to find out which universities you can approach and what their rules are. However, it does give the possibility for the occasional researcher (as I was) to register a series of six to 10 published papers as evidence of research at PhD level. The challenges are to put together a series of papers which develop a single story, and to ask any co-authors to confirm the amount of work you did for each paper. You will also need to write a covering summary of the papers. In my case, the papers were published over a 10- to 12-year period, but the process of applying for, and gaining, the PhD took 2 years from registration. You will still have to defend your PhD at a viva!

Yours sincerely,

TONY DENMAN
Emeritus Professor of Medical Physics,
University of Northampton, UK
Academic careers: permanent member of staff

Peter Hoskins¹ and Stephen Keevil² conclude their academic career series with a look at the permanent member of staff, from lecturer through to professor.

This is the third and final article on academic careers. The first article covered the PhD student, and the second article covered the research assistant and the research fellow. This article is on the full-time academic from lecturer to professor.

The terms ‘academic staff’ and ‘academic’ will be used as abbreviations for ‘permanent academic member of staff’.

Some 3.5 per cent of UK PhD students will become academic staff in universities. The UK grades for academic staff in the older ‘pre-1992’ universities are lecturer, senior lecturer, reader and professor. In newer universities, senior lecturer is effectively a higher grade of lecturer and there is also a principal lecturer grade. In other countries, titles such as ‘assistant professor’ (equivalent to lecturer) and ‘associate professor’ (equivalent to senior lecturer or reader) are used, and ‘associate professor’ has now been adopted in some UK universities.

The work of an academic is divided between three main areas, corresponding to the three main functions of a university: (1) research, (2) teaching and (3) commercialisation and knowledge exchange. The percentage of time spent in each area will vary during the career of an academic. Promotion (covered below) is dependent upon achieving success in one or more of these areas.

Table 1 shows the 2014 income for Edinburgh University, 17th in the world top 20 league table of universities.

The working year

The three major income streams in the table are associated with teaching and research, which historically have dominated the work of academics. New lecturers will (should!) have a very good track record in research. They will have much less experience in teaching (though some research fellow posts ramp up the teaching load during the fellowship). The new lecturer will be expected to contribute to teaching and in parallel develop their own research group.

A new lecture of 1 hour typically requires 5–20 hours of preparation, plus delivering the lecture and follow-up with students. Historically, teaching was seen by many academics as being an annoyance, something which took them away from their research and which they did with the minimum of effort. Nowadays, considerable emphasis is rightly placed on the student experience. There is a consequent demand on academics to provide the student with high-quality teaching. New lecturers, unfamiliar with the discipline of teaching, may be required to undertake courses in teaching theory and practice, including the option to sign up to gain a teaching qualification such as a postgraduate certificate. The experience of many academics with heavy teaching loads is that this dominates their life during term-time and they struggle to devote adequate time to other activities such as research, administration and professional duties. The life of an academic involved in teaching follows the same pattern that they were familiar with as undergraduates. The beginning of the year is mid September, corresponding with the new intake of students. The end of the year is June, when all exams are completed and marked. The completion of exam boards followed by graduation ceremonies in July leads to an emptying of departments. Undergraduates go home and staff take their summer break. Departments which were busy with students and staff a few weeks before are now almost deserted. Committees shut down, emails reduce, staff have more time to attend to their research groups, and have time to write papers and grants. All feels calm for a few weeks and then activity gradually increases as the new academic year approaches. There are exam resits, marking exams, exam ceremonies in July leads to an emptying of departments. Undergraduates go home and staff take their summer break. Departments which were busy with students and staff a few weeks before are now almost deserted. Committees shut down, emails reduce, staff have more time to attend to their research groups, and have time to write papers and grants. All feels calm for a few weeks and then activity gradually increases as the new academic year approaches. There are exam resits, marking exams, exam boards and most importantly students returning on the first day of term in mid September, and the new year begins again. This pattern is less clear in medical schools, where student vacations are much shorter and academics have less of a respite from teaching over the summer.

The academic must initiate and sustain a research group. Academics are not provided with an annual budget from their university to do research. They have to gain funding to undertake research from grant-giving bodies. New lecturers might begin their full-time academic career by doing their own research using shared equipment or

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
</tr>
<tr>
<td>Funding Council grants</td>
</tr>
<tr>
<td>Tuition fees and contracts</td>
</tr>
<tr>
<td>Research grants and contracts</td>
</tr>
<tr>
<td>Other operating income</td>
</tr>
<tr>
<td>Endowment and bank interest</td>
</tr>
</tbody>
</table>

---

¹Professor of Medical Physics and Biomechanics, Edinburgh University
²Consultant Physicist, Guy’s and St Thomas’ NHS Foundation Trust; Professor of Medical Physics, King’s College London

www.ipem.ac.uk

IPEM SCOPE | JUNE 2016 | 27
Through collaboration. However, the expectation is that grant applications will be written to gain funding. As the research group grows over the years, the academic has less and less time to undertake their own research (or decides that they don’t want to do hands-on research anymore) so moves to managing a research group.

Academics must expect to spend a large amount of their time writing grant applications. The overall research council success rate for grants is around 30 per cent, with higher rates for strategic bids and lower rates of 3–10 per cent for project grants. A typical project grant might take 2–3 man-months to work up. If the academic has a 10 per cent success rate and does nothing but write grants for 2 years, they can expect to get one grant funded. This means that across the UK, an enormous amount of staff time is spent on writing grant applications which will be rejected. Academics tend to regard the grant funding system as being effective and well designed when they get their grants funded, and inefficient and outdated when their grants are rejected. Academics can choose two strategies for grant funding. In the first they have an area they are keen to work on, then look for funding opportunities. In the second they see what grant-giving bodies are focussing on and align their grant applications accordingly. Needless to say, success rates are much higher for the second approach. An academic career typically lasts over 30 years. Entire research fields can come and go in this time, and the academic must be prepared to shift their research direction, even changing fields into new and emerging areas. Some academics with expertise in generic areas such as fluid mechanics can simply change their application area (e.g. from industrial to biomedical applications). This makes it relatively easy to supervise students and RAs (Research Assistants) in the new area as the physics and engineering is very similar. Changing fields to a completely new area is more difficult if it lies outside the technical expertise of the academic. This is a common feature of bioengineering research and a team-working approach involving collaboration with other academics is essential in order to provide supervision of all the key technical areas of a project.

Many different skills are necessary for successful management of a research grant and of PhD students: project management, financial management, staff management, student supervision, to name just a few. Usually, the PI (Principal investigator) of a grant is given considerable authority. The PI must operate within the rules of the grant-giving body, and there are big differences in these rules between different bodies which the PI must be aware of. The PI must also operate within the rules of the university. It is the PI who has authority over staff working on a grant. The PI is accountable for the scientific delivery of the grant (in the form of the final report and associated journal papers) and for ensuring that there is no financial mismanagement. New academics are strongly advised to attend as many courses as they can on management relevant to grants and supervision of PhD students. Courses which assume everything behaves like clockwork from start to finish are of limited use. Good courses should provide advice on what happens when things go wrong.

In grant-funded research the time between initiation of a good idea and publishing the work can be many years. A grant takes 3–18 months from idea to submission. Smaller project grants involving a single RA can be put together in a few months. Larger, complex grants involving multiple partners and multiple RAs can take 12 months or longer. The review process is 6–9 months. If successful, it takes 2–3 months for the award letter to be released and an account to be created in the university, from which the funds can be drawn. Advertising, interviewing, appointing and waiting for RAs and PhD students to work their notice period typically takes 6 months, longer if a visa is required. The new RAs may need training if their background is in a different area and they will need to familiarise themselves with the work and get up to speed. The first papers appear 6–18 months after the start of the grant. All of this gives a long timeline of 2–3 years between an idea and the first papers being submitted, or longer for more complicated grants. This timeline can appear glacially slow to new lecturers who, having undertaken their own research as an RA, will have had much faster times of 3–12 months between an idea and paper submission. This slow process also means that the entire field has shifted considerably between the idea and starting the work of a grant. What was a novel project when it was initiated may now have been done by several groups in different parts of the world. In the authors’ experience, these other groups are often much bigger and have much better funding! These delays are part of the current process of grant funding. There are grant schemes which are designed to short-circuit this glacially slow approach.Whilst every researcher wants large flexible funding, these schemes are only open to a tiny minority of extremely successful PIs. These grants have a broad remit, allowing the PI to respond more quickly to new opportunities than the standard project grant will allow.

**Academic grades**

The various academic grades are described here in an abbreviated form with respect to research.

**Lecturer.** Has own independent research programme, involving own-account research, supervision of PhD student and first grants. Evidence of developing reputation in the field.

**Senior Lecturer.** Has a research group with a developing track record of grant funding and publication. Evidence of national/international reputation in the field.

**Reader.** Has an established research group and a track record of grant funding and publication. International reputation in the field.

**Professor.** Has an established research group and a substantial track record of grant funding and publication. Clear evidence of leadership in the field at an international level and an international reputation.

In the past promotion in the university was dependent on research activity, with little account being taken of teaching. The modern university recognises the contribution to teaching and most UK universities have promotion criteria based on teaching right up to professorial level. Due to word constraints, the teaching career path is not further explored and the remaining discussion below is with respect to the research academic path.

The definitions of the academic grades above referred to grant funding, size of the research group and reputation in the field. How are these to be evaluated in a manner which allows decisions to be made concerning promotion, and in a wider context concerning the success of an academic
A few popular metrics are described here.

**Grant funding**. Research-intensive universities are extremely large businesses. Major UK universities have a turnover of around £1 billion per year; consequently, those PIs who can bring in the money tend to get on in their career. Some universities have guidelines for academics at an individual level for obtaining grant income, e.g. a professor should bring in £100k per year. This can be challenging when there are wide variations in grant success. Other universities have criteria at the departmental level, meaning that a period of low grant success for the individual is not unduly problematic. In medical physics and bioengineering, a successful PI might have £600k of current grants equating to a group of two RAs and two PhD students. Stellar PIs can have huge income in the millions of pounds and research groups of 50+ researchers.

**h-index**. This is an index of the impact of the researcher’s publications in terms of the number of times their papers have been cited by other researchers. For example, an h-index of 20 means that the researcher has been an author on 20 papers, each of which has been cited at least 20 times. The h-index increases throughout the career of an academic, and is highly field dependent. In medicine, the h-index of a professor is typically 50+, in medical physics and bioengineering it is 20+ and in engineering 10+.

**Number of peer-reviewed journal papers**. Historically, this has been the easiest metric to quote. A simple web of knowledge search reveals how many papers have been published. Professors in medical physics and bioengineering might be expected to have 50+ journal papers. In recent years there has been less emphasis on this metric with the pressure to publish in journals with a high impact factor. However, for many academics it is still an easy and relevant metric to quote.

**Opportunities for promotion**

When seeking promotion the academic should consider their current and other institutions. In their current institution the academic can put themselves forward through the promotion process which usually requires discussion with and support from the head of department. It can sometimes be useful to test the water, as feedback is provided on what the academic needs to do to meet the promotion criteria, which then allows the academic to focus on these aspects before resubmission. When moving institution, posts can be advertised and applied for in the normal way. It is also common for an academic to approach a university to discuss a possible move. In these circumstances the key currency which the academic offers is the amount of grant money they can bring with them, especially if this is a good fit with the research interests of the new institution. When an academic moves it is usual for most of their research team to move with the academic. This can be resisted by the host university as they lose equipment, grants and staff and usually there is a process of negotiation. Some grant-giving bodies assign the grant to the PI who has the right to take the entire grant to the new institution.

When the academic has a transportable fellowship (which can be awarded to permanent members of staff) or has just landed a large grant, these are the times at which the academic should look to see where they want to be located longer term. Does the current institution offer the right career opportunities or should the academic consider moving elsewhere? Is the current city where the academic wants to live long-term or do they want to live elsewhere? This process of moving research groups between universities happens all the time and the academic should feel no guilt in using this method to their advantage.

**What happens next?**

Sustaining a research group over many decades can be challenging. Rejection of several grants in a row is followed by shrinkage of the group and loss of key expertise, in some cases ending particular avenues of research. Universities offer sabbaticals, where the academic spends time in another lab in the UK or abroad. This can help the academic gain new skills and new collaborations which can then be used in grant applications. Long-term lack of grant success will lead to a reduction in publications. The various metrics against which the academic is judged in research assessment exercises will not be met. Universities do go through periods of shrinkage and the academic without a research group may volunteer for severance, opt for early retirement or in some cases be made redundant. Many academics judge that a research-only post is more high risk than a combined teaching–research post. When grant funding goes down the academic can opt to take on more teaching duties.

The final paid stage of the academic career is that leading up to retirement. Academics will have built up experience and skills over a lifetime. Many academics use the last 2–3 years of their working life to hand over to the younger generation, assisting collaborators and members of their research group in grants that they will lead. Following retirement some academics stay on in an unpaid associate role (for professors this is called ‘Emeritus Professor’). They maintain access to library facilities and may have a desk to work at. Some retired academics continue to write papers and be involved as part of another academic’s research group. Others use the university more for pastoral purposes, maintaining contact with colleagues.

This brief article has described the career of the full-time academic. It has mainly discussed the research career with a lesser emphasis on teaching. The academic needs to be mindful of the various metrics against which their performance is evaluated, and which are relevant for promotion and continued tenure. The academic must be prepared to change field to take advantage of new opportunities, and to change institution when the opportunity arises. Combined teaching–research positions are less risky than research-only positions, but come with challenges of overload during key teaching times. Many academics never really retire, they just stop receiving a salary.
Absorbed dose is the fundamental quantity underpinning all radiotherapy treatments. As a physical quantity it can be definitively measured and quantified. However, actual treatment doses are more ambiguous since the absorbed dose is dependent on the material irradiated. This has led to variation in clinical practice as to whether the treatment is prescribed to the medium itself or to water. These two options for reporting absorbed dose are known as dose to medium (Dm) and dose to water (Dw).

This inconsistency in clinical practice has a close parallel (but is distinct from) the move from type A to type B dose algorithms. That change spurred radiotherapy physicists to communicate the physical underpinning of treatment dose calculations and quantify the clinical differences. We should therefore be similarly engaged with understanding how and where Dm and Dw are different, and know when this difference can be significant.

How are they different?
The development of different dose definitions is closely tied to the history of treatment planning systems (TPS). Historically, the first available definition was the absorbed dose to water in a water medium, which can be represented as Dw,w. This estimate is calculated by correction-based methods (such as PDDs and TPRs). It was from this estimate that traditional radiotherapy clinical experience was derived.

In recent decades, the development of sophisticated dose algorithms – such as collapsed cone and Monte Carlo – has enabled modelling of radiation propagation and energy deposition in generic inhomogeneous materials. The dose calculated by these algorithms is therefore specific to the inferred material in the voxel, i.e. the dose to medium.

To bridge across this change in clinical practice an alternative dose to water was also developed – the absorbed dose for a small cavity of water embedded within the medium, denoted as Dw,m. This dose type is estimated by algorithms such as the analytical anisotropic algorithm (AAA), or can be produced alongside the Dm calculation. It is this definition that we will refer to by Dw in the rest of this article.

Where do they differ?
Dm and Dw for a given voxel can be related using cavity theory (assuming the voxel does not perturb the fluence). This has typically been implemented following Siebers et al.’s usage of Bragg-Gray cavity theory, i.e. \( D_{w,m} = D_{m} s_{m/w} \) where \( s_{m/w} \) is the ratio of water to medium unrestricted mass stopping powers. Since most tissues types are water-like, Dw is only 1–3 per cent higher than Dm which can be considered clinically inconsequential. For example in cortical bone Dw can be 10% greater than Dm - see [1,6] for more information on other tissue types.

Why both are used clinically
The absorbed dose calculated by different TPS varies depending on the dose algorithms (a selected guide is provided in table 1). Therefore, necessity and availability have been major drivers for the clinical use of both Dm and Dw.

However, the fundamental question as to which provides the best indicator of overall biological effect is uncertain. Arguments for the use of Dm and Dw were summarised in a Point–Counterpoint article. In short, some advantages of using Dw are:
- It is consistent with absorbed dose to water–based dosimetry Codes of Practice (CoP).
- It minimises intravoxel dose considerably different from water [i.e. atypical elemental compositions] where Dm and Dw are significantly different.
JUNE 2016

AXB can calculate dose to medium and estimate dose to water. AAA algorithm estimates
collapsed cone calculates dose to medium. Pencil beam estimates dose to water.
CCC algorithm calculates dose to medium. Pencil beam estimates dose to water.

In contrast, some advantages of using Dm are:
- It is a more accurate measure of the dose a patient receives as it is
  the medium that is being irradiated, not water.
- Estimating Dw from Dm involves additional assumptions
  which increases dose uncertainty.

A motivation for the original development of Dw was continuity
with prior clinical practice derived from correction-based algorithms.
However, as an argument for continued usage this has been
diluted over the last two decades by the increased usage of Dm.
For example the fractionation
schedules in the CHHIP and
IMPORT HIGH trials (which will
potentially impact many future
radiotherapy prescriptions) are
open to both types of dose
estimates. However, this is less
likely to be the case for OAR
constraints or TCP and NTCP
parameters which often draw from
the pre-1990 era of universal use
of Dw-w-based estimates.
This debate has been reflected in
radiotherapy guidance documents.
AAPM Report 105 on Monte Carlo
planning acknowledged that there
were significant reasons for either
approach and was therefore non-

prescriptive on which was used
clinically. ICRU Report 83 also
discussed the topic and
recommended the sole use of Dw.

The dose to what medium?
Whether there is any difference
between Dm and Dw depends on
how different the medium is from
water. Whether that difference is
significant hinges on the reliability
with which the actual medium can
be determined.

The dosimetric importance of
plausible variations in material
properties was investigated in
Andreo6 (incorporating and
significantly expanding upon the
work of Ma and Li7). For typical
tissue types this was found to be
important in terms of the electron
fluence and stopping powers.
However, the effect on the
absorbed dose was small (~2 per
cent) as these variations largely
cancel. Therefore, for most tissue
types the difference between Dw
and Dm is comparable with the
intrinsic dosimetric uncertainty
associated with assigning a
medium, even aside from the
uncertainty associated with CT
-calibration8 or variations in the
performance of the dose algorithm
(which can also relate to Dw, Dm)9.

Nevertheless, perturbations in
the fluence have important
consequences for Bragg-Gray
cavity-based methods of
estimating Dw from Dm. Andreo6
investigated the accuracy of this
conversion and found that using a
new fluence correction factor gave
significantly improved Dm-Dw
conversions. This factor is
therefore equally relevant to
centres using Dw or Dm (i.e. when
comparing to Dw based dosimetry
measurements).

When is this clinically
relevant?
In Siebers et al.,10 using a single
head and neck patient plan it was
shown that although changing
between Dm and Dw had a small
effect on the resulting DVH,
individual isodose lines could be
substantially changed. Dogan et
al.11 presented studies based on
sets of head and neck and
prostate patients and found that
although changing dose type
caus ed ~2 per cent variation in the
prescription dose (D95), the mean
value was only marginally
different. The effect on other dose
indices such as maximum dose
(D2) and bony structures,
however, was more significant.

Whether Dw or Dm should be
used for these bony structures
was investigated in Walters et al.12
Here, micro-CT images of bone
anatomy were combined with
human phantom CT images to
investigate the doses to individual
tissue types within the bone. It was
found that the difference between
Dm and Dw was typically small (~5
per cent). However, for cases
where there was a difference (e.g.
cranial) Dw was a significantly
better indicator of the dose to
sensitive tissues. Usmani et al.13
quantified the difference between
Dm and Dw for a set of spinal
 treatments. They recommended
that Dw be used for target voxels
as it represents the dose to the
infiltrating soft tissue tumour cells
in the bone. Dm could be used for
OARs as it represents the average
dose to the voxel.

These studies of bone and
spinal irradiation are particularly
relevant to the recently launched
Commissioning through
Evaluation (CtE) programme, since
this includes spinal and bone
treatments. As a case study we
have demonstrated the relevance
of the difference between Dm and
Dw by replicating the planning
process that would be followed by
two hypothetical centres, one
using Dm, the other Dw. In
particular, we have created
treatment plans for the CtE spinal
benchmarking patient in Monaco
v5.1 as a dual-arc 6 MV VMAT
delivery on an Elekta Agility linac
based on a 240y in 3# prescription.

Simply comparing the dose
distribution for the same plan
could potentially misstate the
impact of using either Dm or Dw as
the trade-off between target and
sparing objectives will have been
altered. We have therefore
optimised using the quoted dose
type for each plan. To ensure a
consistent comparison we have
compared both plans under one
dose type (arbitrarily chosen to be
dose to water), hence we have
recalculated the Dm optimised
plan as Dw (whilst keeping the MU
fixed).

In figure 1 we show a dose
subtraction plot which shows that,
as expected, most of the difference
is concentrated in the bony
medium. We can observe this
effect in the resulting DVHs shown
in figure 2. For the target volume
we see a ~2 per cent increase in
D50 for the Dm optimised plans.
However, under Dm we also see an
increase in the hottest doses to the
Cauda Equina PRV due to the
inclusion of bone. Therefore,
depending on clinical priorities and
the steepness of the NTCP/TCP
curves, different evaluations of
these two plans could be made.
This shows the potential for
complex differences between
clinical plans produced under Dm
and Dw.

| TABLE 1. Commonly used TPS and their dose types |

<table>
<thead>
<tr>
<th>TPS</th>
<th>Dose type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monaco</td>
<td>Dose to medium calculated by default. Option available to estimate dose to water</td>
</tr>
<tr>
<td>Oncentra Masterplan</td>
<td>Collapsed cone calculates dose to medium. Pencil beam estimates dose to water</td>
</tr>
<tr>
<td>Tomotherapy</td>
<td>C/S CC algorithm implementation can be considered dose to medium</td>
</tr>
<tr>
<td>Pinnacle</td>
<td>CCC algorithm calculates dose to medium</td>
</tr>
<tr>
<td>Eclipse</td>
<td>AXB can calculate dose to medium and estimate dose to water. AAA algorithm estimates dose to water</td>
</tr>
<tr>
<td>Raystation</td>
<td>Collapsed cone calculates dose to medium. Pencil beam estimates dose to water</td>
</tr>
<tr>
<td>iPlan</td>
<td>Option available to calculate dose to medium or estimate dose to water</td>
</tr>
</tbody>
</table>

www.ipem.ac.uk
First clinical in vivo application of prompt gamma range verification system, for a proton treatment

Uncertainties in the range of proton beams, known as range uncertainty, currently leads to larger than necessary target volume margins and a restriction on the choice of beam angles. It is widely accepted within the proton therapy community that providing a method to minimise the range uncertainty is crucial to the long-term success of proton and ion therapy.

There are many sources of range uncertainty, but measurement of the proton range within the patient, in vivo, offers a solution to minimise these. Two options exist for this measurement. When protons interact with nuclei in the body they undergo inelastic scattering, leaving behind an excited nucleus. On the timescale of picoseconds (hence the use of the word ‘prompt!’), the nucleus de-excites by the emission of a gamma ray(s).

In cases where the remaining nucleus is radioactive, positron emission tomographic imaging may be possible, but this suffers from issues with biological washout. In this work, the authors, of Oncoray and IBA, investigate the use of prompt gammas to verify the proton range.

The emitted prompt gammas were recorded using a knife–edge-shaped slit camera with a 10 cm FOV (figure 1). Within the camera was an array of scintillators that could detect gamma rays of energy 3–6 MeV. The patient being treated was a 60-year-old male with adenoid cystic carcinoma of the left salivary gland. A 24 Gy-RBE proton boost was delivered with passive scattering to the primary tumour and lymph nodes, prior to a photon IMRT treatment. For seven fractions of the proton boost, prompt gammas were collected for one of the three treatment fields, as shown in figure 1. A consequence of using passive scattering is the production of neutrons in the treatment head, which can subsequently produce additional gamma radiation. These were removed by subtraction of a separate background measurement with the slit closed. This particular patient was selected because the large volume gives a high ratio of prompt gamma signal to neutron background and the angle of the field allows for the slit camera to be positioned orthogonally. Inter-fractional changes in detector sensitivity were accounted for with daily background measurements in a water phantom following each fraction. As an independent measure, diagnostic in-room CT scans (on rails) were acquired for three of the seven fractions. Following manual rigid registration with the planning CT, the nominal plan was recalculated on these additional datasets to monitor dose distribution changes due to anatomical changes.

The prompt gamma signals can be seen in figure 2. Over the seven fractions, the shift of the NET prompt gamma signal was found to vary between –2.0 and +1.3 mm. To ensure that these

**REFERENCES**


2 AAPM Report 105. Issues associated with clinical implementation of Monte Carlo-based photon and electron external beam treatment planning.

3 ICRU Report 24. Determination of absorbed dose in a patient irradiated by beams of x or gamma rays in radiotherapy procedures.


6 Andreo P. Dose to ‘water-like’ media or dose to tissue in MV photons radiotherapy treatment planning: still a matter of debate. Phys Med Biol 2015; 60: 2619.

7 Ma C-M, Li J. Dose specification for radiation therapy: dose to water or dose to medium? Phys Med Biol 2011; 56: 3073.


Pigeon Detection

Researchers in the US have shown that, using differential food reinforcement, pigeons can be used to spot breast cancer. After 15 days of training, the birds’ accuracy in identifying calcifications rose from 50 per cent to 72–84 per cent. However, they were unable to differentiate between benign and malignant masses.

doi:10.1371/journal.pone.0141357

Dissolvable Implants

A silicon-based implant, capable of monitoring temperature and pressure in the brain, has been developed at Washington University School of Medicine. Following trauma, swelling and pressure can be assessed by the bioresorbable device, minimising the potential for allergic reactions, infections and haemorrhages.

doi:10.1038/nature16492

Inhalation Route

The administration of nanoparticles (NP) by an inhalation route (IR) has been shown to increase the dose to lung tumours more than when an intravenous (IV) administration is used. Comparing to the tumour dose without gold NPs, the dose enhancement was 1.51 with IR and 1.15 with IV.

doi:10.1088/0031-9155/60/18/7035

Predicting Noise

A method has been developed in which the noise in a CT image is estimated based on the water-equivalent diameter of the patient. Across 83 clinical image sets, the discrepancy between the developed technique and an independent method was 6.9 per cent when using an iterative reconstruction method.

doi:10.1118/1.4938588

REFERENCE


doi:10.1016/j.ijrobp.2007.01.063


doi:10.1016/j.radonc.2016.01.004.
Editors Comments
This work is undoubtedly one of great importance to the proton therapy field. The capability to measure the proton range in the patient, the uncertainty of which is one of the primary contributing factors in current treatment target margins, is of great benefit. Never before has the proton range been measured in vivo in a patient using the detection of prompt gammas, with all previous studies being conducted in phantoms or via simulations. The authors demonstrated the ability of their system to detect shifts in the position of the prompt gamma signals to within ±2 mm. The treatment margin recipe utilised at their institution, owing to range uncertainty, is 3.5% of the nominal range + 2 mm, which computes to 6.7 mm for this particular field. It is very feasible that this technology could allow for this treatment margin to be substantially reduced in the future.

As stated in their discussion, the current design of the apparatus limits the sites in which it can be utilised; however there is potential for the camera to be mounted to the treatment head in the future. The authors intend to use the camera for pencil beam scanning, which would allow for individual spot information and absolute range evaluation (rather than relative shifts).

More Information

If you have a comment on this article, or would like to share your experiences with the medical physics community, then please get in touch with me via email: paul.doolan@uclh.nhs.uk

Scope Vacancies
SCOPE Editorial Board
One of the aims of Scope magazine is to bring to you content that will have a positive impact on the lives of our patients by way of service improvement. One way we achieve this is by highlighting papers, which discuss introduction of cost effective treatment techniques and method. The practices are based on peer-reviewed journals, which have had a successful outcome.

In continuing the good work of Scope, we now have two vacant positions at the Board level of IPEM Scope magazine.

Applied Academic Editor
Are you an academic and a practicing clinical scientist? Do you have what it takes to commission new features? Can you improve the patient outcomes by bridging academia and clinical practice? Can you engage our avid Scope readers? If so, we would like to hear from you!

We are currently recruiting for a volunteer editor to lead the Applied Academic section. As part of the editorial work, you will work closely with the Editor-in-Chief.


If you are interested in this position, or would like to know what it entails, then please get in touch with Usman Lula, Editor-in-Chief of IPEM Scope via email (usman.lula@uhb.nhs.uk) or with the current joint editors of the sections.
Clinical engineering is a career that involves design, development, support and management of medical devices. With such a broad definition, the scope of the clinical engineer can encompass a number of roles within a hospital, including rehabilitation engineer, gait lab analyst and device design engineer. In this article, I will look at the role of the clinical engineer within the context of a hospital medical device management service.

**Introduction**

The remit of the clinical engineer within a medical device management service varies and depends upon both the size of the hospital and the structure of the department within which they operate. A large hospital, for example, may have several clinical engineers whose roles are consequently more specialised than their counterparts within a smaller hospital. A hospital that conducts in-house maintenance of many of its medical devices and which engages in the design of new medical devices will likely provide a wider job scope for the clinical engineer than a hospital that outsources maintenance and has no device development allowance.

My role within the medical device management service at King’s College Hospital (a London hospital comprising around 1,000 in-patient beds) is one of three clinical engineering positions. In my view, the role of the clinical engineer is unique. It is one of the few positions within a hospital that is so closely linked to medical devices over the many stages of their lifecycle (figure 1).

**Need and specification**

As highlighted in a feature in the June 2015 edition of Scope, the traditionally viewed lifecycle of medical devices within the NHS spans from procurement to disposal. However, a more complete picture of the medical device lifecycle will also include the activities occurring prior to those medical devices ever seeing the light of day (figure 1).

The functions that medical devices are able to perform and the effectiveness with which they are able to perform them is ever progressing. Therefore, in a hospital, there is a continual need to acquire new medical devices. Whilst these needs are often identified by end users or ‘encouraged’ by manufacturers, clinical engineers can also play a vital role here. Being involved at each stage of the device lifecycle, they have a broad overview of the various needs, including those associated with use, cost, training and maintenance.

From these needs comes a specification. In the vast majority of cases, the specification can be met by a commercial product. However, these only exist where there is a financial incentive to do so. Where there is a clinical requirement, but no existing medical device, the design and development of an in-house device may be required. If the scope of their role and their experience allows, it would, I think, be uncommon for a clinical engineer to refuse such a challenge. Such undertakings, in today’s world, require an understanding of and adherence to relevant standards and legislation.

**Procurement and acceptance**

The level of input from clinical engineers into the procurement process for new medical devices will depend on the scale of the procurement in question. The procurement of just a handful of devices would be unlikely to involve much input other than to, for example, provide a clinician with a recommended model.
Maintenance and repair

Maintenance and repair of medical devices contributes to a significant proportion of a medical device management service’s resources. According to Willson et al., each year planned maintenance and repair costs between 5 and 10 per cent of the purchase price of the equipment. The extent to which the repair and maintenance of medical devices are handled in-house varies considerably between hospitals. At one end of the spectrum, day-to-day management of medical devices is handled entirely by an external company. Whilst outsourcing may appear to divulge the hospital of responsibility, such contracts should be monitored for effectiveness and efficiency.

At the other end of the spectrum, the hospital performs all maintenance and repairs in-house. At King’s College Hospital, a balance is struck, with most small items being maintained in-house and more complex devices (such as scanners or x-ray equipment) being placed on service contracts. The balance between in-house and external maintenance of devices is continually shifting based upon staff, cost and space resources. This itself introduces the additional problem of deciding which devices are best suited to a service contract, a problem I think that clinical engineers are in an excellent position to address.

For devices managed in house, clinical engineering can play a role in determining the frequency and level of maintenance required. With the increasing financial restrictions placed on hospitals, attempting to strike a compromise between risk and cost has become a delicate balancing act. Such a balance should be based upon the perceived risk of a particular device and the medical equipment management department’s experience of its reliability.

Although not an inevitable part of the equipment management lifecycle, the investigation of adverse incidents involving medical devices can consume a significant amount of a clinical engineer’s time. Adverse incidents can relate to an endless range of issues, from the wrong settings entered on an infusion pump to poor image quality on a scope. Being able to understand how medical devices work and what is likely to have been the cause of the incident is crucial. During investigations, the clinical engineer provides updates to users, manufacturers and the MHRA, potentially driving change in user training or manufacturing processes.

Reviewing the need and disposal

Venturing into some hospitals and seeing the ages of the medical devices still in use, it may come as a shock that, at some stage, the need for a particular medical device is reviewed. The need to replace a model may arise due to a range of reasons, including excessive maintenance requirements, poor clinical performance, obsolescence or a requirement to standardise to another model.

Disposal of medical devices is more complicated than is often perceived. It is important before disposing of equipment that it is indeed the hospital’s equipment to dispose of, and that it is not on loan from the manufacturer. This is one area where proper management of the equipment database pays dividends. Assuming the device is owned by the hospital, disposal can mean auctioning it (via a specialist auction company), donating it to a charity or by scrapping it.

Summary

This article has described the role of the clinical engineer in terms of many aspects of the medical device management lifecycle. A requirement and a consequence of this is that the clinical engineer has knowledge of the various devices they work with and an understanding of how those devices fit into the complex hospital environment. I think that this puts them in an excellent position to not only contribute to the day-to-day management of medical devices, but to answer some of the important questions in the current NHS climate of limited resources; questions related to the purchase of new medical devices, the maintenance requirements of existing devices and the extent of service contracts entered into with external companies.

REFERENCES


A brief history of medical devices: non-invasive blood pressure monitors

MICHAEL AYERS | WRITES ➔

![FIGURE 1. Hales’s blood pressure experiment](image1)
![FIGURE 2. Ludwig’s kymograph](image2)
![FIGURE 3. Vierordt’s sphygmograph](image3)
![FIGURE 4. Marey’s sphygmograph](image4)
![FIGURE 5. Vierordt’s sphygmograph](image5)
![FIGURE 6. Deriving the systolic and diastolic pressures from variations in cuff pressure (bottom trace) compared to the Korotkov’s sounds (top trace)](image6)

Examination of the pulse has been around since early Egyptian times. However, actual blood pressure measurements were not conducted until the middle of the eighteenth century, with the experiments of Stephen Hales. Hales’s early experiments concerning the measurement of blood pressure involved observing the rise and fall of blood within a long brass pipe inserted into the artery of a horse (figure 1).

Jean Léonard Marie Poiseuille is well known to engineers and physicists interested in fluid flow. His earlier work, a century after the experiments of Hales’s, included the development of a device consisting of a mercury manometer connected to a cannula inserted into the artery of an experimental animal. This device was able to measure pressure in even very small arteries.

In 1847, a few years after the work of Poiseuille, Carl Ludwig developed a kymograph, a device capable of graphically recording pressure (figure 2). Building on the work of Poiseuille, Ludwig’s device incorporated a pen attached to a float. This was able to write upon a rotating cylinder to produce a plot of blood pressure over time.

First non-invasive measurements

Up until this point, all means of measuring blood pressure had been invasive in nature. For many reasons, the requirement to pierce an artery of the patient is far from ideal. From 1855, this changed. Karl von Vierordt proposed a non-invasive method of measuring blood pressure that involved the application of a counter pressure to the artery via a weight (figure 3). When there was cessation of the pulse (detected by palpation) in the artery distal to the applied pressure, it would indicate that the pressure in the artery was equal to this counter pressure.

The accuracy of Vierordt’s design was subsequently improved upon by Etienne Jules Marey. Marey’s design incorporated a moveable weight allowing the applied pressure to be varied (figure 4). Unfortunately, the complexity of using the device precluded it from gaining widespread acceptance.

Around 1881, Samuel Siegfried Karl von Basch developed a refined version of Marey’s device incorporating a small rubber cap placed over the radial artery (figure 5). This method was further adapted by Scipione Riva-Rocci to incorporate a cuff that was wrapped around the entire arm, causing the artery to be compressed from all sides.

The auscultatory technique

Thus far, the use of palpation to determine the point at which blood flow ceases within the artery had limited the devices to the measurement of systolic pressure (the maximum arterial pressure during contraction of the heart). In 1905, Nikolai Korotkov developed a technique that could also reliably measure diastolic pressure (the minimum arterial pressure during relaxation of the heart). Korotkov’s method involved listening to the sounds caused by blood flow distal to the cuff using a stethoscope. Following the increasing of cuff pressure until blood...
flow distal to the cuff was completely restricted, the first sounds heard through the stethoscope when decreasing the cuff pressure indicated the return of blood flow. This corresponded to the systolic blood pressure. The pressure within the cuff was further decreased until no sound could be heard through the stethoscope, indicating an unrestricted flow of blood, corresponding to the diastolic pressure.

The oscillometric technique
An alternative to the auscultatory technique also emerged in the early twentieth century. The oscillometric technique is based upon small fluctuations in cuff pressure. Specifically, reducing the cuff pressure from a point where blood flow is completely restricted distal to the cuff, the first fluctuations in cuff pressure correspond to systolic pressure. The point at which these fluctuations stop decreasing in amplitude corresponds to the diastolic pressure (figure 6).

Whilst the principles of the early oscillometric blood pressure monitors remain largely unchanged, today such devices operate automatically, employing electronic pumps and pressure sensors. Their ease of use has led to the replacement of auscultatory monitors within most clinical settings. Their current widespread acceptance, however, should not hide the fact that there are a number of well-reported concerns pertaining to the use of such devices. Principle amongst these is the fact that the algorithms employed by manufacturers are not standardised. Thus, the determination of systolic and diastolic pressures can be based on various different criteria, which are often not validated against gold standard invasive blood pressure measurements.

Continuous non-invasive measurement
A limitation of all non-invasive blood pressure monitors thus far discussed has been their intermittent nature. Non-invasive devices that are able to provide continuous monitoring of blood pressure, without the risks associated with invasive methods, are now available. One example of this, the volume clamp method, first described by Jan Penáz in 1973, employs an inflatable finger cuff. An infrared transmission plethysmograph within the cuff detects changes in artery diameter (due to increased blood flow and blood pressure). The cuff is inflated or deflated in order to oppose this pressure change and maintain artery diameter. From the cuff pressure, blood pressure is derived (figure 7).

Figure 7. The volume clamp method

REFERENCES
During a recent trip to our Neo-Natal Intensive Care Unit, I was struck by a chirping chorus of alarms echoing around the department. After the visit, I entered the relative quiet of the corridor and began to wonder if the clinicians were able to tell the difference between the high- and low-priority alarms, and how they could possibly manage to attend all of them. A 2013 article by Maria Cvach et al. aimed to address the issues. The article was published in Nursing Management and is based on research carried out at the Johns Hopkins Hospital in Baltimore, Maryland, USA. The hospital is a non-profit academic medical centre with around 1,000 beds.

The article discusses a systematic approach for identifying and controlling some of the problems associated with the management of medical device alarms in a clinical environment. Data, relating to the effectiveness of their control measures and recommend strategies, is presented which may benefit other institutions looking to improve the way that their medical device alarms are managed. Here, we take a brief look at what the researchers found and discuss whether the findings are relevant for a typical NHS Trust hospital in the UK.

For the last 4 years, the Emergency Care Research Institute (ECRI) has rated inadequate medical device alarm policies and practices as the number one health technology hazard. ECRI ranks the issues based on the frequency, severity, preventability and profile of reported adverse incidents and the opinions of a multidisciplinary team. In 2016, it sits at number two on their list – this is a problem that isn’t going away.

Data has been published over the last 20 years which suggests that between 85 and 99 per cent of alarm signals generated by medical devices are false or clinically insignificant. If this data is representative, we have the potential for a boy-who-cried-wolf relationship between medical device alarms and clinicians.

Better known as alarm fatigue, clinicians can become desensitised to alarms due to the sheer frequency that their ever-expanding inventory of equipment is beeping at them. In critical care environments, it is not uncommon for alarms to sound hundreds of times per patient, per day.

Where nuisance alarms are attended, clinicians’ valuable time is wasted and higher priority alarms may be missed. The potential dangers have been well documented, with alarm systems accounting for 216 patient deaths in the USA over a 5-year period. The US-based Joint Commission received 98 alarm-related event reports between January 2009 and June 2012, 80 of which resulted in death, 13 in some permanent loss of function and five in the provision of additional care.

First, Maria Cvach’s team formed an alarm committee who looked at the reasons why alarms were missed, using a fault tree analysis. The multidisciplinary team (consisting of clinical engineers, nursing directors/specialists from each unit, IT staff and risk management specialists) identified seven separate failures that can cause alarms to be missed (alarm not recognised, alarm fatigue, insufficient training, late response, poor equipment user interface, low-staffing and equipment failure). See figure 1 above.

Results from the study
Clinical engineering provided the alarm committee with a weekly alarm report, based on extracted monitor alarm data. The report helped to highlight the high number of duplicate alarms and cases where alarm thresholds were set to non-actionable levels. With some small adjustments to default settings, the report helped to reduce the number of alarms per bed per day from a maximum of 771 alarms in ICU to an average of ~100. The data provided in the report was also used as a valuable education tool for clinical staff. It is not clear, though, how resource-demanding.
it was to collect and analyse all of this data each week.

Clinical engineering also provided the committee with an alarm inventory. This consisted of department-specific and device-specific alarm settings for devices that, according to the FDA and clinical expertise, were associated with higher numbers of alarm-related deaths. Unsurprisingly, these devices included cardiac monitoring equipment, infusion pumps and ventilators (all of which should have a planned preventative maintenance schedule).

Guidance

The inventory also provided guidance for clinical staff on: how to prioritise alarms, which staff can change alarm settings, methods for secondary alarm notifications and who can turn alarms off and when. The infrastructure at Johns Hopkins allowed alarms to be distributed to staff’s wireless devices based on priority and suitable response times. They also provided the facility to escalate alarms to senior staff if needed. This helped to reduce the frequency of alarms on their surgical wards by 53 per cent and reduced alarm response times by 23 per cent.

An alarm review was also incorporated into the hospital’s electronic medical records system, which helped remind staff to review alarm settings at least once per shift. This led to a 24 per cent reduction in the frequency of alarms in their critical care unit.

As a collective, these alarm management strategies saw an overall reduction in the number of cardiac monitor alarms by between 37 and 79 per cent across the hospital.

COMMENT BY JIM GOULD

At face value, these results are very encouraging for any hospital thinking of reviewing their current medical device alarm management strategy. However, local issues such as staffing levels, hospital infrastructure, budget restrictions and the hospital’s political landscape may limit the application of some of the strategies suggested by Cvach et al. For example, most NHS Trusts are not likely to be in a position to invest in hundreds of staff pagers and/or a complete WiFi infrastructure. It is also worth pointing out that the effects of the alarm management strategies on patients and staff were not considered here – the reduction in alarms is only useful if clinical outcomes are not deteriorating!

On the other hand, a multidisciplinary alarm committee and an alarm inventory are measures that all Trusts could implement with relatively low financial outlays. The most significant resource needed would be that of staff time. But given the seriousness of the issue and the improvements documented here, it is certainly worthy of consideration.

REFERENCES

For these meetings and other conferences organised by IPEM, abstracts and presentation slides, where the speakers have given their permission, are available at: http://www.ipem.ac.uk/Members/TrainingandOtherResources/IPEMConferencepresentations.aspx

SPECIAL REPORTS

Unfortunately, not all of the reports written by recipients of IPEM’s bursaries, as well as attendees of other meetings of interest, can be published in Scope due to space constraints, and so the following reports have been uploaded to IPEM’s website, at the address given above. Covering a wide range of topics presented at meetings held quite literally across the globe, they are well worth a read.

- Multi-modality Routine Image Quality Assessment: QC/ QA and Standards (14th October 2014) by Amber Gislason-Lee (London, UK)
- 15th International Congress of Radiation Research (25th–29th May 2015) by Kamran Fathi (Kyoto, Japan)
- AAPM Summer School on Proton Therapy: Physical Principles and Practice (14th–18th June 2015) by Ana Lourenco (Colorado Springs, USA)
- 7th International Workshop on Breast Densitometry and Cancer Risk Assessment (10th–11th June 2015) by Oliver Morrish (San Francisco, USA)
- XIII European Association of Thermology Congress (3rd–5th September 2015) by Constanzo Di Maria (Madrid, Spain)
- International Research Council on Biomechanics of Injury (8th–11th September 2015) by Paul Harrington (Lyon, France)
- Digital Breast Tomosynthesis Workshop (11th September 2015) by Jamie Douglas (Vienna, Austria)

These workshops and conferences brought together internationally recognised speakers to present on the clinical applications and current research topics relating to breast density, shown to be an independent risk factor for breast cancer as well as contributing to a reduction in the sensitivity of mammography. Presentations were delivered by a wide range of professionals (radiologists, epidemiologists, physicists) as well as patients.

For these meetings and other conferences organised by IPEM, abstracts and presentation slides, where the speakers have given their permission, are available at: http://www.ipem.ac.uk/Members/TrainingandOtherResources/IPEMConferencepresentations.aspx
Welcome all! We have three interesting reviews in this issue. A list of the titles with reviewers can be found in table 1. There are a number of new medical physics and popular science textbooks in the ‘Just Published!’ section, such as Healthcare Systems Engineering which teaches how to approach the healthcare industry as a complex system and the application of relevant design and engineering principles and processes to advance improvements. Leading High Reliability Organisations in Healthcare presents concepts and tools to help achieve safety, quality and efficiency goals in a hospital setting.

The ‘New Reports and Newsletters’ section lists a number of new reports, including two from the IAEA on ‘Cyclotron Produced Radionuclides’ and ‘Good Practice for Introducing Radiopharmaceuticals for Clinical Use’. An update to the usual ‘Safer Radiotherapy’ report is also provided. The links to the latest medical physics newsletters from around the world can be found in this section.

Urgent request! We would like to increase our current numbers of book reviewers to fulfill our quarterly target of seven book reviews. Reviewing counts towards your CPD (see ‘Self-directed learning’, HCPC Guidance to Standards for CPD – duties as a registrant). Moreover, reviewing a book means you get to keep it. As part of the reviewing process, we use an online collaboration tool known as Wiggio, offered free by Desire2Learn, in which reviewers will find a list of the latest book reviews and book request status. The tool is also used to upload book reviews and for all Scope activities.

If you would like to review a book or have a comment on any part of the Scope magazine then please Tweet us!

Mr Usman I. Lula is a Principal Clinical Scientist based in Radiotherapy at the University Hospitals Birmingham NHS Foundation Trust, UK
Email: Usman.Lula@uhb.nhs.uk

The e-book The Pioneering of e-Learning in Medical Physics was launched at the World Congress in Toronto and the MPEC Conference in Liverpool, where it received the President’s Prize for the best oral presentation. The e-book gives a brief description of the chronology of seven EU-funded international medical physics educational projects (1994–2014) which are among the first to develop and introduce original e-learning in the teaching process.

The e-book starts with the first International Conference on Medical Physics Education and the first EMERALD project, which was developed before the existence of the terms e-learning and e-books. EMERALD created some of the world’s first ISBN-numbered electronic image databases (on CD-ROM) and e-books. Currently, the results of the EMERALD and EMIT (training tasks for the physics of: diagnostic radiology, nuclear medicine, radiotherapy, ultrasound and magnetic resonance imaging) projects are used by some 2,500 colleagues per month through the http://www.emerald2.eu website. The book also shows an example of continued success in international collaboration. The first project EMERALD, described in the book, was initiated in 1994 by a small, enthusiastic team of about 15 ‘pioneers’ from the UK, Sweden, Italy, Portugal, Ireland and Bulgaria, and in 10 years the final project EMITEL attracted more than 300 specialists from 36 countries, making it the largest international project in the profession. Altogether, the projects described in the book attracted about 400 participants, contributors and supporters (their names are listed in the relevant chapters). The results achieved could not have been possible without the hard work and ideas of all these colleagues. For this reason, the authors of the book (S. Tabakov and V.

<table>
<thead>
<tr>
<th>Book title</th>
<th>Reviewer</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Pioneering of e-Learning in Medical Physics</td>
<td>Slavik Tabakov</td>
</tr>
<tr>
<td>Imaging and Imagining the Fetus</td>
<td>Francis Duck</td>
</tr>
<tr>
<td>Using Medicine in Science Fiction</td>
<td>Elizabeth Berry</td>
</tr>
</tbody>
</table>
Tabakova), who were at the heart of the co-ordination of all these projects and kept a diary of their development, dedicated the material to all project contributors and supporters.

The book consists of 202 pages, with 134 images, diagrams and consortium photos. It gives an overview of the development of e-learning materials, as well as sufficient information of the ideas/concepts, their implementation into medical physics training / education, and the challenges and successes of the international project team. The book underlines the successes of the projects, based on the excellent collaboration of so many colleagues from different countries. This has boosted the dissemination of the projects’ results and has contributed to the increased visibility of medical physics. The book includes peer feedback from many specialists about the application of e-learning in the educational process (specifically in medical physics), as well as the views of the authors for its further development.

The original intention of this book was primarily to be used by the project contributors as a record of their international collaboration. However, the e-book shows an example of introducing e-learning in one profession (medical physics) and the significant global impact of this process for the profession. Obviously, for this reason it has triggered external emphasis it places on the details of the work.

Of the 10 million ultrasound scans performed each year in NHS Trusts in England, about a quarter are for obstetrics and gynaecology (O/G). Put another way, there are about the same number of O/G ultrasound scans as there are MRI scans. This book is about how that all started, in Glasgow, in the 1950s. It recounts how two talented mavericks, the obstetrician Ian Donald and the engineer Tom Brown, worked together to create the Diasonograph, the commercially successful ultrasound scanner that created a new discipline: fetal medicine. This historical narrative stands out from many accounts in the history of medicine because of the emphasis it places on the details of the engineering development, without which Donald’s conception would never have been delivered.

The authors form a successful partnership. Nicholson is Director of the Centre for the History of Medicine at the University of Glasgow, and so brings a broad historical perspective. John Fleming joined Tom Brown as a development engineer in the early 1960s, and later established the historical collection of the British Medical Ultrasound Society (BMUS). It is his personal contribution to the engineering development of ultrasound scanning, and his connection with the individuals involved in its early years, which makes this book a unique record.

Medical ultrasound drew on techniques and technologies developed during the Second World War: echo-ranging and position indication from radar and sonar; high-frequency ultrasonic technology from metal flaw detectors. Howry and Ried in the USA and Mayneord at the Marsden were already exploring ultrasound for cancer diagnosis.

Others looked at echoes from the heart. But it was Ian Donald in Glasgow who focussed specifically on the challenge of obstetric scanning, at first to differentiate between cystic and solid abdominal masses, and later for fetal imaging.

There is a delightful, and convincing, account of the authors’ reconstruction of the early bench-top experiment using a Kelvin Hughes flaw detector on excised masses, suggesting that Donald’s enthusiasm, and unfamiliarity with the instrument, led him to see what he wanted to see, and disregard the rest. Never mind – it was sufficient to carry the work forward. The Diasonograph was the first medical ultrasound scanner to be designed for O/G. Smiths shipped 12 of these instruments before production was taken over by Nuclear Enterprise in Edinburgh. Tom Brown is shown to have been an engineer whose concepts were ahead of his time. Having launched the Diasonograph he designed and constructed an automatic scanner to replace the hand-scanned original design, anticipating automatic real-time scanning. He set the electronic controls under a cover, to prevent fiddling, anticipating modern standard presets. Later, his early 3D scanner anticipated future developments. His view was that doctors should be released from engineering constraints, with instruments able to generate standardised and optimised output. This is perhaps the greatest challenge of all bioengineering design.

The book includes archive ➤
acknowledgements, and there is now additional help on medical topics in the form of this book, which is specifically targeted at writers of science fiction. The advantage of this book over an adviser with more general medical expertise is that the author has already taken the step of considering issues, then applying his knowledge, from a science fiction perspective. So the book has chapters including topics such as suspended animation, microgravity, sex in science fiction, telepathy and immortality.

The author is well qualified to write such a guide; he is both an experienced cardiologist and a science fiction author, and is also studying physics and astronomy at undergraduate level. This balance of skills is reflected in the content of the book. On the subject side, there is an emphasis on medicine and biology, with physics and engineering treated at a relatively basic level. On the writing side, each chapter has a section (‘The Bottom Line’) dedicated to exploring the ways that authors might include the chapter topic in their work. The advice here demonstrates a recognition of the range of approaches in which one can get the medicine right, and still write an enjoyable story. The author is clearly well read in the genre – throughout, there are many examples from science fiction.

The opening chapter is called ‘How the human body works: from quarks to cells’, so it is perhaps not surprising that it seems to squeeze in too much information. Later chapters are less condensed, and as a result are more enjoyable. For those who are not writers they provide a snapshot of current space science and related research. The book will probably be best used as a reference text, but it is certainly not a textbook. You can tell this from the remarkably low price, the lack of illustrations and the footnote comments that range from straightforward definitions to wry comments with sci-fi allusions.

Although aimed at writers, the book should also appeal to readers of sci-fi (especially those of a nit-picking persuasion), and perhaps to those looking for unusual nuggets of information to enliven their teaching or everyday conversation.

Dr Elizabeth Berry, Elizabeth Berry Ltd, Berwickshire, and a tutor for the Open University

**Using Medicine in Science Fiction: The SF Writer’s Guide to Human Biology**

H.G. Strathmann (editor)

Publisher: Springer

ISBN-13: 978-3-319-16014-6

Format: Softcover

Pages: 556

Price (publisher’s website): £15.00

When the credits roll at the end of a blockbuster movie, or an episode of a science fiction series on TV, the name of a science or medicine advisor may be glimpsed as the list rapidly flashes by. For the written word, subject experts often feature in book
Computational Biomechanics for Medicine by Grand Joldes, Barry Doyle, Adam Wittek, Paul M. E. Nielsen and Karol Miller (Springer) provides an opportunity for specialists in computational biomechanics to present their latest methodologies and advancements. This volume comprises 18 of the newest approaches and applications of computational biomechanics, from researchers in Australia, New Zealand, the USA, the UK, Switzerland, Scotland, France and Russia. Some of the interesting topics discussed are: tailored computational models; traumatic brain injury; soft-tissue mechanics; medical image analysis, and clinically relevant simulations. One of the greatest challenges facing the computational engineering community is to extend the success of computational mechanics to fields outside traditional engineering, in particular to biology, the biomedical sciences and medicine.

The History of Science by Massimo Mazzotti (Taylor & Francis) addresses crucial questions through a selection of exemplary publications spanning antiquity to the present day. The collection brings together areas of inquiry that have become increasingly distant and specialised, such as the history of antique science or Cold War studies, within broader narratives of the making of the modern world. They also reassess the traditional assumption of the exclusively Greek and Western origins of modern science, situating relevant knowledge, practices and artefacts within the global networks that sustained them: in ancient as well as in modern times. The gathered materials address key historiographical issues, such as the relationship between science, magic and religion; the role of science in nation-building processes, and the relationship between science and technology.

Healthcare Analytics by Eva K. Lee and Hui Yang (John Wiley & Sons) provides an integrated and comprehensive treatment of recent research advancements in data-driven healthcare analytics in an effort to provide more personalised and efficient healthcare services. Emphasising data and healthcare analytics from an operational management and statistical perspective, the book details how analytical methods and tools can be utilised to enhance care quality and operational efficiency. Contributions from well-known international experts shed light on new approaches in this growing area, and numerous real-world examples and case studies emphasise the vast potential of statistical and operational research tools and techniques to address the big data environment within the healthcare industry.

Healthcare Systems Engineering by Paul M. Griffin and Harriet Black Nemhard (John Wiley & Sons) is the first engineering book to cover this emerging field, offering comprehensive coverage of the healthcare system, healthcare delivery and healthcare systems modeling. Written by leading industrial engineering authorities and a medical doctor specialising in healthcare delivery systems, this book provides a well-rounded resource for readers from a variety of backgrounds. Examples, case studies and thoughtful learning activities are used to thoroughly explain the concepts presented, including healthcare systems, delivery, quantification and design. You’ll learn how to approach the healthcare industry as a complex system, and apply relevant design and engineering principles and processes to advance improvements.

Assessing Competence in Professional Performance Across Disciplines and Professions by Marcia Menitkowski and Paul F. Wimbers (Springer) examines the challenges of cross-professional comparisons and proposes new forms of performance assessment to be used in professions education. It addresses how complex issues are learned and assessed across and within different disciplines and professions in order to move the process of ‘performance assessment for learning’ to the next level. In order to be better equipped to cope with increasing complexity, change and diversity in professional education and performance assessment, administrators and educators will engage in crucial systems thinking. The main question discussed by the book is how the required competence in the performance of students can be assessed during their professional education at both undergraduate and graduate levels.

Leading High Reliability Organisations in Healthcare by Richard Morrow (Taylor & Francis) presents concepts and tools that a growing number of hospitals are using to help achieve their safety, quality and efficiency goals. The author includes numerous case studies to demonstrate successes and failures of concepts and tools discussed in the book. The Institute of Medicine and others have stressed the urgency of transforming hospitals into places where each patient receives the best quality care, every single time. Hospital leaders agree that they need to change their systems and processes in order to achieve substantial increases in reliability, and leadership is the most important ingredient in increasing the reliability of an organisation.

Basic Clinical Radiobiology, 5th Edition by Michael C. Joiner and Albert van der Kogel (Taylor & Francis) is a concise but comprehensive textbook setting out the essentials of the science and clinical application of radiobiology for those seeking accreditation in radiation oncology, clinical radiation physics and radiation technology. Fully revised and updated to keep abreast of current developments in radiation biology and radiation oncology, this fifth edition continues to present in an interesting way the biological basis of radiation therapy, discussing the basic principles and significant developments that underlie the latest attempts to improve the radiotherapeutic management of cancer.

Einstein at Home by Friedrich Herrneck and Josef Eisinger (Prometheus Books) provides candid descriptions of the private life of Albert Einstein from a series of interviews with Herta Waldow, a housekeeper who lived with Einstein and his wife and daughter from 1927 to 1933 at their residence in Berlin. After the Second World War, science historian Friedrich Herrneck interviewed Ms Waldow and published the conversations in the former East Germany. Unavailable in English until now, these five interviews offer fascinating glimpses into the great scientist’s daily routines while he lived as a celebrated...
Challenges by Vera A. Khokhlova and Lawrence A. Crum (Springer) provides a thorough introduction to the fundamental physics and current state-of-the-art in therapeutic ultrasound. Expert chapters present theoretical and experimental methods and review characteristic parameters of transducers, tissue properties, acoustic fields, induced bioeffects and clinical applications. The book also reviews ultrasound and MR-based imaging methods used to monitor treatments; transducer designs, including a description of current devices and applications, and histological and biochemical methods to analyse the therapeutic effect of ultrasound.

### reviews

- Good Practice for Introducing Radiopharmaceuticals for Clinical Use. IAEA TECDOC No. 1782; 2016.
- Medical Device Alerts Archive, Medical Safety Alert. MHRA; 2016.
- HCPC in Focus. HCPC; February 2016.
- IPEM Trainees’ Network Newsletter. IPEM; March 2016.

### radiation & rf shielding, MR & X-ray imaging accessories

- **Structural X-ray & Gamma Shielding**
- **RF & Magnetic Shielding for MRI**
- **MRI Patient Monitoring**
- **Bespoke Engineering** Monitor Stands, Drugs Trolleys, Scoliosis Chair, Step Platforms
- **Exports** Agents in over 40 countries
- **PREMADEX® Neutron Shielding**

---

**T** • +44(0) 20 8398 9911
**F** • +44(0) 20 8398 8032
**E** • sales@wardray-premise.com
**W** • www.wardray-premise.com

Quality without Compromise from the UK’s leading radiation shielding company
It was also very exciting seeing so many different types of equipment and where they are used, including lots I’d never seen before.

A day in the life...
She said she has been surprised by how much she cares about the patients and feels part of the team on the unit. ‘Although I look after the machines that are needed for our patients, I don’t care for them directly myself, like the nursing staff do. But I really care about them and often see the parents of children who have been with us for a while. You do build up a relationship with them, which I didn’t expect.’

Hannah is given close support by the Medical Equipment Management Service who are on hand to assist at any time. ‘It does get very, very busy,’ she says, an experience that will be familiar to anyone working in a hospital environment. ‘Managing the expectations of colleagues is really important. But people are very understanding and are so supportive.’

She says her training helped with this: ‘I really learned a lot during my training, which was much more hands on than I’d expected. I thought it would be much more shadowing, so that was quite unexpected and exceeded my expectations.’

 Asked to describe her typical day, Hannah says it starts with a handover. ‘There are all the daily checks to do, calibrations, top-ups and the nursing staff telling you what has gone wrong during the night and will need fixing before it can be used again that day. Then the rest of the day is taken up with setting equipment up, covering breakdowns, liaising with the Medical Equipment Management Service and dealing with whatever comes up really. It can be really varied. But I’ve been able to make the systems for the equipment on the unit my own, which is really good.’

Hannah says her ambition is to do further training and become as good as she can in her profession. And her advice for future trainees?

‘Try your hardest, even if you are struggling, and keep persevering. Even if, at the end, you decide that particular role isn’t for you, you can build on that knowledge and experience in another role. So keep going and doing your best!’
My undergraduate degree was Chemical Physics (MSci) at the University of Bristol. The course suited me really well as I studied a range of topics covering chemistry, physics and maths, all of which I enjoy. Over the course of my degree I became increasingly interested in imaging and, although my only hands-on experience of imaging was using a confocal microscope to image colloidal particles during my final-year project, I decided that I wanted to learn more about different imaging techniques and applications.

The Physical Sciences of Imaging in the Biomedical Sciences (PSIBS) Centre for Doctoral Training (CDT) at the University of Birmingham seemed like the perfect PhD course for me. During the first year, as part of an MSc programme, we had a range of lectures covering the physical sciences, biology and computer science, and completed three 8-week projects spanning these areas before then choosing a PhD project. I decided to continue my final 8-week project as my PhD research.

I am currently developing a multimodal imaging system which is capable of bioluminescence tomography (BLT), diffuse optical tomography (DOT) and also has a built-in three-dimensional surface capture system (the imaging system was initially built by a previous student at the PSIBS CDT). I am currently updating the DOT component of the system and have plans to add fluorescence imaging (FLI) capabilities. Whilst this is not a clinical imaging system, which is different to anything I have ever done before. Seeing the first images taken with a DOT system that I built myself was really exciting.

I have been very lucky to go to a number of conferences where I have given both oral and poster presentations, including one in Hawaii! It has been fantastic to visit places that I wouldn’t otherwise have been to.

**Ambitions for the future**

I have applied for the NHS Scientist Training Programme (STP) to start in 2016. I have been interested in medical physics for a number of years and I am excited to apply physics in a medical environment where many people will directly benefit from my work.

During the MSc year of the PSIBS CDT, I undertook an 8-week project looking at the use of Cerenkov imaging as a potential method for dose monitoring in radiotherapy. As part of this project, I had the opportunity to work in a hospital environment and interact with both researchers and clinical scientists. This was something I particularly enjoyed as I was able to spend some time working in an area of research which I see as a potential career path.

**Skill set acquired**

A large amount of my PhD project involves skills and techniques that I was originally unfamiliar with, and because of this I am becoming much more confident in tackling problems that initially seemed out of my skill set. For example, before starting at the University of Birmingham I had very little experience in computer science, and had never used MATLAB or LabVIEW software before. Now I use both every day. My imaging system is controlled using LabVIEW, which I have recently used to write a GUI (graphical user interface) to control the DOT component of the system, whilst all of the data processing for the system is done using MATLAB. I have also used MATLAB to modify the reconstruction algorithm used to process BLT data.

As well as computer science, my practical skills have also developed during the course of my PhD. I really enjoy the practical aspects of my work and I like getting stuck in to all areas of my project. As mentioned earlier, the imaging system I am developing is for use in preclinical research, namely small animal studies. However, before the system can be used to perform this research it is important we know that it works in the way that we want it to. So far I have only done post mortem work, but I have completed relevant Home Office modules and have a personal licence for doing in vivo small animal studies. I think it is important to be able to do as much as possible myself in order to be self-sufficient and also gain a better understanding of my work.

My self-confidence and confidence in my abilities have developed throughout my PhD. Even when I don’t initially know how to tackle something I am now happier to take on new challenges, problem solve and learn as I go than when I started the PhD. My presentation skills have also improved considerably. I was initially a very nervous presenter, but I am far more confident and experienced now because I have had plenty of opportunities to practice my skills.

**Writing papers, issues**

Writing papers is an area where practice makes perfect. I have submitted a number of abstracts to conferences, which were in the form of short papers, and had my first paper from my PhD research recently published in the *Journal of Biomedical Optics*. This was the first paper where I took the lead role in writing and collating the results. I had to make a number of changes to the text and re-run some simulations before it was accepted, but having been through the process I now know what to expect for next time.

The style of writing that these abstracts and papers requires takes some getting used to; it has to be scientific and concise yet descriptive enough to get all of the information across in a clear manner. The more documents you write, the more natural this style of writing becomes.
t is with great sadness that the editorial
board of Physiological Measurement reports
the passing of its former Editor-in-Chief,
Michael R. Neuman MD, PhD. All who
worked with him on the journal, and in
the field in general, enjoyed working with
him immensely and he will be sorely missed.
Mike faithfully served the journal as Editor,
board member and latterly International
Advisory Member for almost 20 years, and in
that time advised us through times of great
change. His great breadth and depth of
knowledge is almost unrivalled and he leaves
an unfillable hole in our boards.

Sense of humour
One of Mike’s favourite Physiological
Measurement stories concerned his interview
for the position of Editor, or Honorary Editor
as it was then. During the telephone
interview, Mike was asked what he would do
to improve the Impact Factor of the journal.
His answer was that he would publish a bad
paper, his logic of course being that a bad
paper would be cited greatly in all of the
follow-up work, either commenting on it or
disproving it. This answer was met with a
few moments of stunned silence before
laughter ensued. Needless to say, Mike was
offered the job despite his tongue-in-cheek
idea to improve the Impact Factor.

This dig at the Impact Factor system
typified Mike’s wry sense of humour that
pervaded all of our dealings on the board. He
will be sadly missed by the board and by the
community, but he has left behind a legacy to
the profession that will endure.

Mike’s colleague and friend Professor John
G. Webster was kind enough to write a few
words to help us understand Mike’s
impact on the field and on those
around him, and these words
are a fitting way to end.

In a lunch line at an IEEE
EMBS Conference in Philadelphia
about 1972 I met Michael Neuman
and several other academic
biomedical engineers
(BMEs). We lunched
together and moaned that
there was no suitable text to teach medical
instrumentation. We agreed to meet in my
room that evening, and argued for 2 hours
about chapter titles that were agreeable to all.
Then we each selected the chapters we would
like to write. Mike wrote three chapters for
our much-used text: Medical Instrumentation:
Application and Design. In addition to his 248
publications, Mike went on to perform
exceptional leadership for BME.

Working life
‘Mike was Editor-in-Chief, IEEE Transactions
on Biomedical Engineering, 1989–1996, and he
was Editor-in-Chief, Physiological
Measurement, Institute of Physics Publishing,

‘Mike was also an exceptional friend. We
would go to London for the annual editorial
meeting of Physiological Measurement.
Afterward with his wife Judy and my wife
Nancy we explored the culture of Reims and
Brugge, another year Stuttgart and Munich,
and another year enjoyed a U-drive canal
boat near Birmingham.

‘Along with Stuart and Claire Meldrum we visited Mike’s home in Houghton,
Michigan, USA, where he and Judy kept	hree ponies and eight goats as pets, toured
copper mines, and took a scenic side boat trip
to Isle Royale.

‘Mike lived a rich and much accomplished
life. We will surely miss him.’

ACKNOWLEDGEMENTS
Jon Ruffle
IOP Publishing, Temple Circus
Temple Way
Bristol BS1 6HG
Jon.ruffle@iop.org

John G. Webster
University of Wisconsin – Madison
College of Engineering
Room: 214B
Engineering Centers Building
1550 Engineering Drive
Madison, WI 53706
USA
webster@engr.wisc.edu
HISTORICAL FEATURE: UPPER LIMB PROSTHESES

Soldiers without arms: upper limb prostheses in WWI

Francis Duck (University of Bath) tells the story of how the prosthetic limb industry brought innovative products to wounded soldiers during and after the war.

The 1914 edition of A.A. Marks’ Manual of Artificial Limbs1 shows the interior of the seven-storey Marks factory, 701 Broadway, New York City, claiming it to be the ‘largest artificial limb manufactory in the world’. Whether this claim was true or not, it represents the state of the prosthetics industry when war was declared in Europe, in August of that year. This article briefly tells the reason for the domination of the industry by the USA before the war, and how the deluge of mutilated soldiers changed the future of prosthetic design and provision.

The USA leads the way

Photographs of WWI amputees are amongst the most telling records of the mutilating legacy of the war. Historically, wars have always generated maimed veterans, but never before in such numbers. The American civil war, which ended in 1865, caused its own amputees. Manufacturers such as A.A. Marks and J.E. Hanger benefited from an 1862 law granting one free limb to every honourably discharged veteran. Then, whilst similar European enterprises remained cottage industries, these American companies turned their attention to damaged civilians, who lived in an increasingly affluent but dangerous country. With burgeoning industrialisation and agricultural mechanisation, unfenced railways and trams, unregulated mining and manufacture, the number of civilian amputations grew. To quote Marks: ‘The electric trolley has maimed more than the horse-cars of a decade ago. The mowing machine and the reaper have cut off more limbs than the scythe, dynamite has mutilated the human body more than the black powder of former days’. Marks’ marketing aimed at private amputees worldwide, offering a mail-order service supported by ‘how-to’ instructions for stump measurement. Pre-war Britain was a slower, safer place: of 5,483 operations carried out at St Thomas’s Hospital in 1913, only 34 were amputations.2

The materials that Marks used to construct the artificial arms and legs were largely the same as those used in the rest of the prosthetics industry: legs were made of wood with brass hinges and arms of leather braced with steel. The designs were fairly unsophisticated, even preferring a rigid to an articulated ankle. Marks used more rubber than other manufacturers, on the soles of the feet, and a rubber hand that was primarily cosmetic, and was always covered with a glove. The fingers could be positioned using the other hand. Small utensils and pens could be secured, and the thumb could be worked against a spring by means of a cord attached at the shoulder (figure 1).

However, engineering design was following a demand for improved function. By the beginning of the war, a number of artificial arms of considerably greater complexity had been designed, of which the Carnes arm was the most notable (figure 2). It was designed by the mechanic William Carnes from Kansas, after he had lost his right arm above the elbow in 1902. Commercial development followed a US patent in 1911. The articulated wrist could be moved to any position, flexion or extension, pronation or supination, using the sound hand. An intricate mechanism, built within the steel hand, was controlled by two cords, powered by shoulder movement. For above-elbow amputation, one cord controlled the movement of the elbow and the second the digits, one pull to extend them and a subsequent pull to return them to flexure. For below-elbow amputation, both cords were available, one to extend and the other to flex the fingers. The reason for the success of the Carnes arm was its combination of function with form. Many amputees, especially those from the upper echelons of society, wished first and foremost to disguise their deformity, and to be able to eat and drink without assistance or embarrassment. The Carnes arm filled this need. But it was expensive, and heavy.

War in Europe

The flood of mutilated soldiers returning home to Britain, France, Germany and other warring nations was a huge logistical challenge. One estimate gives 67,000 war-time amputees amongst the German casualties. The British figure was slightly less: 41,300 officers, non-commissioned officers and men lost part or all of a limb, of whom 11,350 (27 per cent) were upper limb amputees.3 Since similar numbers must have occurred in the armies of each of the warring nations, France, Russia, Serbia, Austria and so on, at least a quarter of a million soldiers probably returned home from the front in need of a prosthetic limb. By contrast, only about 4,000 amputees were recorded amongst the US casualties following that country’s late entry to the war in 1917. It is little surprise, therefore, that the design and manufacture of artificial limbs started to move from the USA to Europe. At first, there being no large-scale national prosthetics industry in any of the warring nations, US suppliers filled the need. But it was not long before Europe took over. In Berlin, the Test Centre for Prosthetic Technologies, lead by the engineer Georg Schlesinger, evaluated the available commercial prostheses, and by 1916 the main German product, the
Siemens-Schuckert Universal Arm, had been developed. Others followed; Sauerbruch, Müller, Openshaw, McKay, and several more.

Limb fitting in Britain was carried out at the Queen Mary’s Auxiliary Hospitals, the first centre opening at Roehampton, with fitting workshops for the assembly of imported components. By the end of the war, 24,000 cases had been treated there. British firms, such as Chas A. Blatchford, slowly emerged with several advances in prosthetic technology.3 The first Blatchford patent was awarded in 1916, and was for a clutch to control the elbow lock without the use of the other hand. Later developments included ball-bearing joints, knee control devices and means to reduce ankle shocks. But arm design remained the main challenge. Before the war in the USA, only 15 per cent of the testimonials in Marks’ catalogue were for upper limb prostheses: mobility was far more important to the private customer than manual control. By the end of the war, Blatchford were producing 20 times as many arms as legs. There was a need to get men back to work.

Workers’ hands
In 1868, Dr Armel Grippouilleau, from the School of Medicine in Tours, had presented an innovative design for workers’ artificial arms to l’Académie nationale de médecine. Instead of mimicking the form of the human hand, intended primarily to disguise the deformity, he proposed a prosthesis that ended in a jointed connector to which a variety of tools could be attached (figure 3).4 This approach was quite different in intention to that of the Carnes and similar arms, which were specifically designed to allow middle-class gentlemen and ladies to operate within polite society. Here was an arm for the working man. Arm action was effected from a body harness. A simple hook or ring could be attached, or more specialist tools such as the vine-dresser’s hand and the gardener’s hand. Later attachments were named the plumber’s hand, the postman’s hand and the tram-driver’s hand (figure 4).5 By WWI, Grippouilleau’s design had evolved and had been widely adopted, using screw-in or bayonet fittings, universal joints or engineering chuck fittings, and allowing functional and cosmetic hands to be interchanged (figure 5).

There was a vigorous discussion about the merits of alternative approaches. A question in parliament suggested that discharged soldiers preferred the Carnes arm to the Blatchford arm, and requested that the former should be prescribed on request, probably representing the officers who, at most, wished to use their arm to write, read, eat and smoke a pipe. The debate was also
sociological. References were made to well-wishers who felt that pensioned soldiers should be given clerical jobs, requiring no physical exertion, no matter what their trade or profession had been before the war. Nevertheless, the mainstream opinion was that ‘wherever possible, the disabled man should be retrained in his old trade’. The Ministry of Pensions identified three classes of arms: (1) the heavy worker’s arm, (2) the light worker’s arm and (3) the light dress arm. Seven amputation regions were defined from A, through the shoulder joint, to G, through the wrist joint, giving 21 different types of artificial arm. So, for example, a B3 arm, a light dress arm for an upper arm amputee with a short stump, might be designed so that, for example, ‘when the elbow is bent and locked at a right angle an overcoat can be hung across the forearm’, or an E1 arm for a heavy worker’s below-elbow amputation, designed to take a hook attachment.

Weight

Amongst the technical developments during WWI, possibly the most significant was the use of lighter materials, which retained the strength of the traditional wood and steel. By the end of the war, the average weight of a worker’s arm for amputation below the elbow was about 1.5 kg, and that for a dress arm about 1 kg. The steel Carnes hand alone could weigh as much. The aluminium alloy duralumin had been developed in Germany by the metallurgist Alfred Wilm before the war, and was already being manufactured in Britain by Vickers Ltd. With a density about one-third of steel, comparable strength and the ability to be shaped by rolling and stamping, it was possible to form light and strong prostheses for both upper and lower limbs (figure 6). Plastics also started to be used. The semi-synthetic thermoplastic Celluloid (also called Xylonite) had been patented in 1869. Treated to make it non-inflammable it could be used for light dress or ornamental arms. A new lightweight material known as Certalmid was more widely used, consisting of muslin, celluloid and casein, applied over the plaster cast of a stump or formed into a prosthetic hand (figure 5). Certalmid sockets weighed half as much as those of the same strength made of willow wood covered with rawhide, and a Certalmid hand could weigh as little as 170 g.

How to drive the prosthesis

Control of movement was provided using one or more of three sources of power, exerted through cords, between a body harness and the prosthesis mechanism. These were (1) movement of one or both shoulders, (2) expansion of the chest or (3) movement of the stump within the socket. A very large variety of devices were developed, with varying degrees of acceptability for the amputee. There was, however, a radically different approach which should be mentioned briefly, known as cinematisation, using so-called plastic motors. This was a surgical procedure in which any residual undamaged muscle mass in the stump was drawn out and formed under a skin flap. The flap was created to be a shape and size suitable for the fastening of the hooks, rings or rods, which could then transmit movement to the prosthetic mechanism. Generally, two ‘motors’ were established to work in opposition, so giving mechanical control. However, whilst such ‘plastic motors’ were testament to the skill of individual surgeons, rather like modern hand transplants they did not represent the mainstream of prosthetic development.

Summary

WWI transformed the provision of prosthetics. Most obviously, the centre of gravity moved from the USA to Europe both for need and manufacture. In place of the European cottage industry, based around craftsmen working in small workshops, numerous new businesses appeared. These were often run by, and employed, highly skilled design engineers who created a wide range of patented new mechanisms. Before the war, customers were largely private individuals, and the large US businesses depended on advertising and testimonials to succeed. The war created substantial state support, resulting in a secure business environment in which companies could thrive and test new product designs. Alloys and plastics gave rise to lighter prostheses. Emphasis was placed on the design challenges of arm and hand prostheses. For artificial leg design, cine photography was used in gait analysis. The final and probably the most important change had to do with limb fitting and aftercare. The American mail-order firms left measurement and fitting to the customer. The establishment of large national limb-fitting hospitals such as Queen Mary’s Roehampton and the Prince of Wales Cardiff provided the facilities in which surgeons, engineers, limb fitters and therapists could come together into a multidisciplinary team. The large engineering workshops gave employment to some disabled soldiers, and facilities for experimentation with prototype prostheses. This was the crucial in which modern rehabilitation engineering was born. It was recognised that, without the will of the patient, no amount of rehabilitation engineering, no clever mechanisms, no new materials, could repair a damaged soldier’s spirit. Nevertheless, the close co-operation between engineers, surgeons, support staff and industry, in all the warring nations, helped thousands of victims of the battlefield to rebuild their lives.

REFERENCES

2 Muirhead Little E. Artificial Limbs and Amputation Stumps. London: Lewis, 1922.
Ronald Woolmer was a farsighted academic anaesthetist, as he was deemed on his untimely early death in 1962 at the age of just 54, as a result of pancreatic cancer most probably acquired through the anaesthetist’s habit at that time of sitting at the head of the patient in the operating theatre, and inhaling their exhaled gases. Although his life was short, it was very eventful and productive on a worldwide scale, as was evidenced by his memorial service which completely filled St Martin in the Fields, London, in February 1963.

Father certainly had an interesting and peripatetic childhood. He was born in London on 17th February 1908, the youngest of three lively boys who were constantly rough-housing and getting into mischief. His father was a mining engineer, and at the time was the manager of a number of copper and coal mines in the Ashmolinsk district of Siberia, 1,800 miles east of Moscow and 500 miles south of the Trans-Siberia railway. They were the only European family living in the area under very harsh conditions, the workers being mainly Kirghiz and Russians.

In 1917, Grandfather sent the family home to England to escape the gathering storm of Revolution, a difficult and dangerous journey by train, sled and boat via Finland and the Baltic Sea to the Arctic Circle, and through Norway. Later, Grandfather escaped in his Lorraine-Dietrich car after the house and contents were taken over by the Bolsheviks.

After prep school in Liphook, Father was sent to Rugby School, where his interest in mechanics and electronics developed. From an early age his father had encouraged him to reason accurately and find out how things worked. At the age of 14 he knew he wanted to become a doctor, and perhaps it was this early combination of interests that eventually led to the formation of the BES, now IPEM. He travelled widely, spending time in Europe, Canada and New Zealand, where his mother’s family lived, before returning to study medicine.

He was admitted to University College, Oxford, where he earned an Honours degree, qualifying from St Thomas’s Hospital in 1932 with a BM, BCh. He reputedly worked hard and played hard, with a reputation for never refusing a party or a drink! He took it as a great compliment when told by a fellow student: ‘Of course you did an incredible amount of work while never appearing to do any at all!’ He had wide interests; he won a Blue for boxing and rowed for his college. He joined the Royal Naval Volunteer Reserve and learned to pilot an aeroplane.

In Father’s book, The Conquest of Pain (1961), he describes his first appointment as House Surgeon in the south-west of England, duties for which included the giving of some anaesthetics, in which he had no particular interest at the time. He had been in his new post scarcely an hour when called to give an anaesthetic, not in the OR, but in the x-ray department where reductions of fractured tibia and fibula bones in a lower leg were to be performed under fluoroscopic control. ‘Is there an apparatus there?’, he asked. ‘Lord! No,’ came the answer, ‘you’ll have to use rag and bottle’ (chloroform, which he had never used). ‘And this machine gives off sparks, so ether’s out.’ The patient was a large, muscular policeman and the surgeon required deep anaesthesia for him. As Father dripped chloroform cautiously on a gauze mask he tried to remember all he had been told about anaesthetics. He was unable to get to the wrists to feel a pulse. He continues the narrative: ‘However, I said to myself, I can see that his pupils are normal in size and react to light, his face is a good colour and I can hear him breathing regularly. So long as that’s so, I reckon we’re all right. Just then someone turned the lights out so that the image on the x-ray screen would become clear, and I could no longer see my patient’s colour or pupils. I was consoling myself with the thought that I could still hear his breathing, when a loud whirr started immediately behind me – the x-ray machine’s electric generator. From then on I couldn’t hear the patient’s breathing. I kept on dropping the chloroform and hoping I was giving the right amount… I suppose they weren’t more than a few minutes at the reduction, but it seemed hours to me. At last, satisfied, they switched off the machine and the lights came on again. I hurriedly tried to assess the patient’s condition. Breathing? Regular but shallow. Pupils? Dilated: no reaction to light, his face is a good colour and I can hear him breathing regularly. So long as that’s so, I reckon we’re all right. Just then someone turned the lights out so that the image on the x-ray screen would become clear, and I could no longer see my patient’s colour or pupils. I was consoling myself with the thought that I could still hear his breathing, when a loud whirr started immediately behind me – the x-ray machine’s electric generator. From then on I couldn’t hear the patient’s breathing. I kept on dropping the chloroform and hoping I was giving the right amount… I suppose they weren’t more than a few minutes at the reduction, but it seemed hours to me. At last, satisfied, they switched off the machine and the lights came on again. I hurriedly tried to assess the patient’s condition. Breathing? Regular but shallow. Pupils? Dilated: no reaction to light, Colour? Pale. So was mine, I expect. Anaesthesia was deep and had evidently been getting deeper. I stopped the chloroform, and during the next 10 minutes, while the plaster cast was being applied, the breathing gradually became deeper, and the pupils smaller. By the time they had finished, he was beginning to come round. ‘Thank you,’ said the surgeon, ‘a good anaesthetic’. I tried to look nonchalant as I watched the patient being wheeled away, and reflected how easily the outcome might have been a tragedy. Then and there I resolved to learn all I could about anaesthesia.

From that day he was quite certain that this was what he wanted to do. He said: ‘the fascination of acquiring new skills and mastering new techniques, of helping in the development of surgery, and of applying a …

www.ipem.ac.uk
knowledge of pain relief to suffering humanity, held me in its grip.’ In 1935 he met Marjorie Grant, who was working as a medical secretary at the Radcliffe Hospital, Oxford, when he was appointed house surgeon there. They married in 1937 and lived in London, when Father moved to St Thomas’s, Hospital.

In 1939, war was declared and Father was called back to the Royal Navy. He was sent out on HMS Oxfordshire, a P & O liner converted into a hospital ship, to Sierra Leone. There was little activity there and he had time to write Anaesthetics Afloat and to read all 24 volumes of the Encyclopaedia Britannica twice through! He returned after 2 years suffering from beri-beri, from which he never fully recovered. His next appointment was to the Naval Hospital in Kingseat, near Aberdeen, where he and Mother lived from 1941 until he was demobbed, having attained the rank of Surgeon Commander.

Although they both enjoyed Aberdeen, which had a teaching hospital and a university, there was no Chair of Anaesthetics at that time, so Father obtained a position as Reader in Anaesthetics at the Bristol Royal Infirmary. Cars were almost impossible to get post-war and for several months he had to cycle several miles to the hospital through deep snow, even through the bitter winter of 1947. Eventually, we were permitted a Ford 10 and life became more comfortable after the years of turmoil.

Without sisters, and schooled at boys’ boarding schools, little girls were something of a mystery to Father, and he would arrange birthday treats for us which consisted of thoroughly male entertainment such as motor racing, and then wondered why we preferred to stay and play with our friends in the back garden! But he certainly encouraged a love of science in both of his daughters, and with a workshop on the top floor of our house in Bristol, we would spend hours making radios, thermometers, turning wood and making ghastly smells, and very nearly setting the house on fire on more than one occasion. During school holidays we were often lucky enough to travel with our parents to medical conferences in many European locations, and in the winter to be taken skiing, a sport we still enjoy today. Father always packed War and Peace in his luggage as an insurance policy against breaking a leg, which would have kept him off the slopes. It worked well, as none of us ever had a serious accident. Long car journeys to Scotland and in the summer were less enjoyable, however. In an attempt to stop us from being car-sick, Father would bombard us with mental arithmetic – ‘we are travelling at 36 mph, and have 282 miles to go. What time will we arrive?’ I am sure it was good for us but it didn’t feel like it at the time!

In Bristol, Father was pro-active in setting up the Society of Anaesthetists South Western Branch, and became its President, writing many articles and giving lectures to medical students. His inventiveness and interest in research led to his promotion to Reader in Anaesthetics at Bristol University, and then in 1957 being invited to head the new Research Department of the Faculty of Anaesthetists at the Royal College of Surgeons in London.

Father was thrilled with his new job, but realising his limited knowledge of research techniques he spent several months travelling across the USA, and to other far-flung places, from where he sent us – now at boarding school – a stream of colourful postcards, mostly written in verse, or perhaps doggerel being a more appropriate description, with which we decorated our dormitories.

At his seventh-floor laboratory in Lincoln’s Inn, he and his team developed and manufactured many items of equipment, and Father invented the first mechanical syringe designed for the slow injection of drugs over long periods, and the first dummy, which he named ‘Pneumonica’, for teaching artificial respiration. We visited when we were on our way to and from school, and were asked to help by being guinea pigs for his latest invention, and were rewarded with 10 shillings each time!

So the last 5 years were very rewarding for Father, and he had been invited to South Africa and Moscow to give papers at important conferences in early 1963. We all returned from a visit to Venice and Opatija, Yugoslavia (where Father was demonstrating the first moveable prosthetic ‘Belgrade hand’) and a medical congress in Vienna in September 1962, and knew that Father was ill. He booked himself into St Thomas’ Hospital (of which he was a Governor), but even the massive doses of radiation he ordered were of no help and he died just 3 months later, unable to complete his ambitions for the progress of medical electronics, and the further development of anaesthesia, for which he had done so much since that first episode with a pad soaked in chloroform in 1934.

Among his papers we found the following, to give a flavour of his writing ability and his sense of humour, which had given us so much entertainment during his lifetime.

---

**Doctors and Doctors**

One little doctor, looks you thro’ and thro’,
Can’t diagnose your case, and then there are two.
Two little doctors, failing to agree,
Call a consultation, then there are three.
Three little doctors, poke you o’er and o’er,
Send for a specialist, then there are four.
Four little doctors, wonder you’re alive,
Order in the x-ray man, then there are five.
Five little doctors, trying funny tricks,
Another brings a stomach pump, and then there are six.
Six little doctors, preparing you for heaven,
In comes a DD, then there are seven.
Seven little doctors, decide to operate,
Call in a surgeon, then there are eight.
Eight little doctors, think it is your spine,
Send for a neurologist, then there are nine.
Nine little doctors, all of them are men,
Send for a lady doctor, then there are ten.
Ten little doctors, standing by your bed,
Come to a decision, find that you are dead.

---

**Doctors and Doctors**

A poem written by Ronald Woolmer
MRI Coils

- Flexi Coils; Knee, Ankle, Wrist, Elbow
- Torso
- Shoulder & more...
  Coils compatible with most MRI scanners

Call: 0844 571 0012

Purchase of unwanted radiology equipment including:
- CT • MRI • X-Ray • Ultrasounds • Mammos & more
- Transportation • Deinstallation & Removal • Disposal • Healthcare Construction • CT Rental

Devon Medical Equipment Ltd • enquiries@devonmedical.co.uk • www.devonmedical.co.uk
Beams You Up to a New Era in 3D Water Scanning.

The future in 3D water scanning starts now.

**BEAMSCAN™** – The New Water Phantom.  
Automated • Wireless • Fast  
Explorers wanted.