DEVELOPMENT OF PHYSICS APPLIED TO MEDICINE IN THE UK, 1945–1990

The transcript of a Witness Seminar held by the Wellcome Trust Centre for the History of Medicine at UCL, London, on 5 July 2005

Edited by D A Christie and E M Tansey

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ILLUSTRATIONS AND CREDITS

Abbreviations

AAPM American Association of Physicists in Medicine

AERE Atomic Energy Research Establishment

ARSAC Administration of Radioactive Substances Advisory Committee

BCRU British Committee on Radiation Units and Measurements

BECC British Empire Cancer Campaign

BIR British Institute of Radiology

BJR *British Journal of Radiology*

DMR Diploma in Medical Radiology

HPA Hospital Physicists' Association

HSE Health and Safety Executive

IAEA International Atomic Energy Agency

ICRP International Commission on Radiological Protection

ICRU International Commission on Radiation Units and Measurements

IGE International General Electric

IOMP International Organization for Medical Physics

IPEM Institute of Physics and Engineering in Medicine

IPEMB Institute of Physics and Engineering in Medicine and Biology

IPSM Institute of Physical Sciences in Medicine

ISR International Society of Radiology

MRC Medical Research Council

MRI Magnetic Resonance Imaging

NBS National Bureau of Standards

NHS National Health Service

NIH National Institutes of Health, Washington, DC

NMR Nuclear Magnetic Resonance

NPL National Physical Laboratory, Teddington, UK

NRC National Radium Commission

NRPB National Radiological Protection Board

PET Positron Emission Tomography

PMB *Physics in Medicine and Biology*

PUVA Psoralens with Ultraviolet A

SPECT Single Photon Emission Computed Tomography Scanner

UCH University College Hospital, London

UKAEA UK Atomic Energy Authority

WAW Women against War

WHO World Health Organization

WITNESS SEMINARS:
MEETINGS AND PUBLICATIONS[1]

In 1990 the Wellcome Trust created a History of Twentieth Century Medicine Group, associated with the Academic Unit of the Wellcome Institute for the History of Medicine, to bring together clinicians, scientists, historians and others interested in contemporary medical history. Among a number of other initiatives the format of Witness Seminars, used by the Institute of Contemporary British History to address issues of recent political history, was adopted, to promote interaction between these different groups, to emphasize the potential benefits of working jointly, and to encourage the creation and deposit of archival sources for present and future use. In June 1999 the Governors of the Wellcome Trust decided that it would be appropriate for the Academic Unit to enjoy a more formal academic affiliation and turned the Unit into the Wellcome Trust Centre for the History of Medicine at UCL from 1 October 2000. The Wellcome Trust continues to fund the Witness Seminar programme via its support for the Wellcome Trust Centre.

The Witness Seminar is a particularly specialized form of oral history, where several people associated with a particular set of circumstances or events are invited to come together to discuss, debate, and agree or disagree about their memories. To date, the History of Twentieth Century Medicine Group has held more than 40 such meetings, most of which have been published, as listed on pages xiii–xv.

Subjects are usually proposed by, or through, members of the Programme Committee of the Group, which includes professional historians of medicine, practising scientists and clinicians, and once an appropriate topic has been agreed, suitable participants are identified and invited. This inevitably leads to further contacts, and more suggestions of people to invite. As the organization of the meeting progresses, a flexible outline plan for the meeting is devised, usually with assistance from the meeting's chairman, and some participants are invited to 'start the ball rolling' on particular themes, by speaking for a short period to initiate and stimulate further discussion.

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[1] The following text also appears in the 'Introduction' to recent volumes of *Wellcome Witnesses to Twentieth Century Medicine* published by the Wellcome Trust and the Wellcome Trust Centre for the History of Medicine at UCL.

Each meeting is fully recorded, the tapes are transcribed and the unedited transcript is immediately sent to every participant. Each is asked to check his or her own contributions and to provide brief biographical details. The editors turn the transcript into readable text, and participants' minor corrections and comments are incorporated into that text, while biographical and bibliographical details are added as footnotes, as are more substantial comments and additional material provided by participants. The final scripts are then sent to every contributor, accompanied by forms assigning copyright to the Wellcome Trust. Copies of all additional correspondence received during the editorial process are deposited with the records of each meeting in Archives and Manuscripts, Wellcome Library, London.

As with all our meetings, we hope that even if the precise details of some of the technical sections are not clear to the non-specialist, the sense and significance of the events will be understandable. Our aim is for the volumes that emerge from these meetings to inform those with a general interest in the history of modern medicine and medical science; to provide historians with new insights, fresh material for study, and further themes for research; and to emphasize to the participants that events of the recent past, of their own working lives, are of proper and necessary concern to historians.

Members of the Programme Committee of the History of Twentieth Century Medicine Group, 2005–06

Dr Tilli Tansey – Reader in History of Modern Medical Sciences, Wellcome Trust Centre for the History of Medicine at UCL (WTCHM), and Chair

Sir Christopher Booth – WTCHM, former Director, Clinical Research Centre, Northwick Park Hospital, London

Dr Robert Bud – Principal Curator of Medicine and Manager of Electronic Content, Science Museum, London

Dr Daphne Christie – Senior Research Assistant, WTCHM, and Organizing Secretary

Dr John Ford – Retired General Practitioner, Tonbridge

Professor Mark Jackson – Centre for Medical History, Exeter

Professor Ian McDonald – WTCHM, former Professor of Neurology, Institute of Neurology, London

Dr Helga Satzinger – Reader in History of Twentieth Century Biomedicine, WTCHM

Professor Lawrence Weaver – Professor of Child Health, University of Glasgow, and Consultant Paediatrician in the Royal Hospital for Sick Children, Glasgow

ACKNOWLEDGEMENTS

'Development of Physics Applied to Medicine in the UK, 1945–1990' was suggested as a suitable topic for a Witness Seminar by Professor John Clifton, who assisted us in planning the meeting. We are very grateful to him for his input. Our thanks go to Dr Alan Jennings who also helped us in the planning process. We are particularly grateful to Professor Peter Williams for his excellent chairing of the occasion. We thank Dr Jeff Hughes who read an earlier draft of the transcript and offered helpful comments and advice, and for writing the useful Introduction to these published proceedings. We also thank Mr Bob Burns, Professor John Clifton and Dr Alan Jennings for additional help with the transcript. Mr Tom Ashton, Mr Bob Burns, Professor John Clifton, Professor David Delpy, Mr John Haggith, Dr Alan Jennings, Professor Peter Wells, Professor John West and Professor John Mallard kindly provided the photographs.

As with all our meetings, we depend a great deal on our colleagues at the Wellcome Trust to ensure their smooth running: the Audiovisual Department, and the Medical Photographic Library and Mrs Tracy Tillotson of the Wellcome Library; Mr Akio Morishima, who has supervised the design and production of this volume; our indexer, Ms Liza Furnival; our readers, Ms Lucy Moore, Ms Fiona Plowman, Mr Simon Reynolds and Mrs Lois Reynolds. Mrs Jaqui Carter is our transcriber, and Mrs Wendy Kutner and Mrs Lois Reynolds assist us in running the meetings. Finally we thank the Wellcome Trust for supporting this programme.

Tilli Tansey

Daphne Christie

Wellcome Trust Centre for the History of Medicine at UCL

HISTORY OF TWENTIETH CENTURY MEDICINE WITNESS SEMINARS, 1993–2007

1993	**Monoclonal antibodies**
1994	**The early history of renal transplantation**
	Pneumoconiosis of coal workers
1995	**Self and non-self: A history of autoimmunity**
	Ashes to ashes: The history of smoking and health
	Oral contraceptives
	Endogenous opiates
1996	**Committee on Safety of Drugs**
	Making the body more transparent: The impact of nuclear magnetic resonance and magnetic resonance imaging
1997	**Research in general practice**
	Drugs in psychiatric practice
	The MRC Common Cold Unit
	The first heart transplant in the UK
1998	**Haemophilia: Recent history of clinical management**
	Obstetric ultrasound: Historical perspectives
	Post penicillin antibiotics
	Clinical research in Britain, 1950–1980

1999	**Intestinal absorption**
	The MRC Epidemiology Unit (South Wales)
	Neonatal intensive care
	British contributions to medicine in Africa after the Second World War
2000	**Childhood asthma, and beyond**
	Peptic ulcer: Rise and fall
	Maternal care
2001	**Leukaemia**
	The MRC Applied Psychology Unit
	Genetic testing
	Foot and mouth disease: The 1967 outbreak and its aftermath
2002	**Environmental toxicology: The legacy of *Silent Spring***
	Cystic fibrosis
	Innovation in pain management
2003	**Thrombolysis**
	Beyond the asylum: Anti-psychiatry and care in the community
	The Rhesus factor and disease prevention
	Platelets in thrombosis and other disorders

2004	**Short-course chemotherapy for tuberculosis**
	Prenatal corticosteroids for reducing morbidity and mortality associated with preterm birth
	Public health in the 1980s and 1990s: Decline and rise?
2005	**The history of cholesterol, atherosclerosis and coronary disease, 1950–2000**
	Development of physics applied to medicine in the UK, 1945–90
2006	**The early development of total hip replacement**
	The discovery, use and impact of platinum salts as chemotherapy agents for cancer
	Medical ethics education in Britain, 1963–93
	Superbugs and superdrugs: The history of MRSA
2007	**The rise and fall of clinical pharmacology in the UK, *c.* 1950–2000**
	The resurgence of breast-feeding, 1975–2000
	DNA fingerprinting: From discovery to database
	The development of sports medicine in twentieth-century Britain

PUBLISHED MEETINGS

'…Few books are so intellectually stimulating or uplifting'.
Journal of the Royal Society of Medicine (1999) **92:** 206–8,
review of vols 1 and 2

'…This is oral history at its best…all the volumes make compulsive reading… they are, primarily, important historical records'.
British Medical Journal (2002) **325:** 1119, review of the series

Technology transfer in Britain: The case of monoclonal antibodies
Self and non-self: A history of autoimmunity
Endogenous opiates
The Committee on Safety of Drugs
In: Tansey E M, Catterall P P, Christie D A, Willhoft S V, Reynolds L A. (eds) (1997) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 1. London: The Wellcome Trust, 135pp. ISBN 1 869835 79 4

Making the human body transparent: The impact of NMR and MRI
Research in general practice
Drugs in psychiatric practice
The MRC Common Cold Unit
In: Tansey E M, Christie D A, Reynolds L A. (eds) (1998) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 2. London: The Wellcome Trust, 282pp. ISBN 1 869835 39 5

Early heart transplant surgery in the UK
In: Tansey E M, Reynolds L A. (eds) (1999) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 3. London: The Wellcome Trust, 72pp. ISBN 1 841290 07 6

Haemophilia: Recent history of clinical management
In: Tansey E M, Christie D A. (eds) (1999) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 4. London: The Wellcome Trust, 90pp. ISBN 1 841290 08 4

Looking at the unborn: Historical aspects of obstetric ultrasound
In: Tansey E M, Christie D A. (eds) (2000) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 5. London: The Wellcome Trust, 80pp. ISBN 1 841290 11 4

Post penicillin antibiotics: From acceptance to resistance?
In: Tansey E M, Reynolds L A. (eds) (2000) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 6. London: The Wellcome Trust, 71pp.
ISBN 1 841290 12 2

Clinical research in Britain, 1950–1980
In: Reynolds L A, Tansey E M. (eds) (2000) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 7. London: The Wellcome Trust, 74pp.
ISBN 1 841290 16 5

Intestinal absorption
In: Christie D A, Tansey E M. (eds) (2000) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 8. London: The Wellcome Trust, 81pp.
ISBN 1 841290 17 3

Neonatal intensive care
In: Christie D A, Tansey E M. (eds) (2001) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 9. London: The Wellcome Trust Centre for the History of Medicine at UCL, 84pp. ISBN 0 854840 76 1

British contributions to medical research and education in Africa after the Second World War
In: Reynolds L A, Tansey E M. (eds) (2001) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 10. London: The Wellcome Trust Centre for the History of Medicine at UCL, 93pp. ISBN 0 854840 77 X

Childhood asthma and beyond
In: Reynolds L A, Tansey E M. (eds) (2001) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 11. London: The Wellcome Trust Centre for the History of Medicine at UCL, 74pp. ISBN 0 854840 78 8

Maternal care
In: Christie D A, Tansey E M. (eds) (2001) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 12. London: The Wellcome Trust Centre for the History of Medicine at UCL, 88pp. ISBN 0 854840 79 6

Population-based research in south Wales: The MRC Pneumoconiosis Research Unit and the MRC Epidemiology Unit
In: Ness A R, Reynolds L A, Tansey E M. (eds) (2002) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 13. London: The Wellcome Trust Centre for the History of Medicine at UCL, 74pp. ISBN 0 854840 81 8

Peptic ulcer: Rise and fall
In: Christie D A, Tansey E M. (eds) (2002) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 14. London: The Wellcome Trust Centre for the History of Medicine at UCL, 143pp. ISBN 0 854840 84 2

Leukaemia
In: Christie D A, Tansey E M. (eds) (2003) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 15. London: The Wellcome Trust Centre for the History of Medicine at UCL, 86pp. ISBN 0 85484 087 7

The MRC Applied Psychology Unit
In: Reynolds L A, Tansey E M. (eds) (2003) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 16. London: The Wellcome Trust Centre for the History of Medicine at UCL, 94pp. ISBN 0 85484 088 5

Genetic testing
In: Christie D A, Tansey E M. (eds) (2003) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 17. London: The Wellcome Trust Centre for the History of Medicine at UCL, 130pp. ISBN 0 85484 094 X

Foot and mouth disease: The 1967 outbreak and its aftermath
In: Reynolds L A, Tansey E M. (eds) (2003) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 18. London: The Wellcome Trust Centre for the History of Medicine at UCL, 114pp. ISBN 0 85484 096 6

Environmental toxicology: The legacy of *Silent Spring*
In: Christie D A, Tansey E M. (eds) (2004) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 19. London: The Wellcome Trust Centre for the History of Medicine at UCL, 132pp. ISBN 0 85484 091 5

Cystic fibrosis
In: Christie D A, Tansey E M. (eds) (2004) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 20. London: The Wellcome Trust Centre for the History of Medicine at UCL, 120pp. ISBN 0 85484 086 9

Innovation in pain management
In: Reynolds L A, Tansey E M. (eds) (2004) *Wellcome Witnesses to Twentieth Century Medicine.* Volume 21. London: The Wellcome Trust Centre for the History of Medicine at UCL, 125pp. ISBN 0 85484 097 4

The Rhesus factor and disease prevention
In: Zallen D T, Christie D A, Tansey E M. (eds) (2004) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 22. London: The Wellcome Trust Centre for the History of Medicine at UCL, 98pp. ISBN 0 85484 099 0

The recent history of platelets in thrombosis and other disorders
In: Reynolds L A, Tansey E M. (eds) (2005) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 23. London: The Wellcome Trust Centre for the History of Medicine at UCL, 186pp. ISBN 0 85484 103 2

Short-course chemotherapy for tuberculosis
In: Christie D A, Tansey E M. (eds) (2005) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 24. London: The Wellcome Trust Centre for the History of Medicine at UCL, 120pp. ISBN 0 85484 104 0

Prenatal corticosteroids for reducing morbidity and mortality after preterm birth
In: Reynolds L A, Tansey E M. (eds) (2005) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 25. London: The Wellcome Trust Centre for the History of Medicine at UCL, 154pp. ISBN 0 85484 102 4

Public health in the 1980s and 1990s: Decline and rise?
In: Berridge V, Christie D A, Tansey E M. (eds) (2006) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 26. London: The Wellcome Trust Centre for the History of Medicine at UCL, 101pp. ISBN 0 85484 106 7

Cholesterol, atherosclerosis and coronary disease in the UK, 1950–2000
In: Reynolds L A, Tansey E M. (eds) (2006) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 27. London: The Wellcome Trust Centre for the History of Medicine at UCL. 164pp. ISBN 0 85484 107 5

The development of physics applied to medicine in the UK, 1945–90
In: Christie D A, Tansey E M. (eds) (2006) *Wellcome Witnesses to Twentieth Century Medicine*. Volume 28. The Wellcome Trust Centre for the History of Medicine at UCL. This volume. ISBN 0 85484 108 3

The early development of total hip replacement
In: Reynolds L A, Tansey E M. (eds) (2007) *Wellcome Witnesses to Twentieth Century Medicine. V*olume 29. London: The Wellcome Trust Centre for the History of Medicine at UCL. In Press. ISBN 978 085484 110

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Copies of volumes 21–28 can be ordered from www.amazon.co.uk; www.amazon.com; and all good booksellers for £6/$10 plus postage.

Other publications

Technology transfer in Britain: The case of monoclonal antibodies
In: Tansey E M, Catterall P P. (1993) *Contemporary Record* **9:** 409–44.

Monoclonal antibodies: A witness seminar on contemporary medical history
In: Tansey E M, Catterall P P. (1994) *Medical History* **38:** 322–7.

Chronic pulmonary disease in South Wales coalmines: An eye-witness account of the MRC surveys (1937–42)
In: P D'Arcy Hart, edited and annotated by E M Tansey. (1998) *Social History of Medicine* **11:** 459–68.

Ashes to Ashes – The history of smoking and health
In: Lock S P, Reynolds L A, Tansey E M. (eds) (1998) Amsterdam: Rodopi BV, 228pp. ISBN 90420 0396 0 (Hfl 125) (hardback). Reprinted 2003.

Witnessing medical history. An interview with Dr Rosemary Biggs
Professor Christine Lee and Dr Charles Rizza (interviewers). (1998) *Haemophilia* **4:** 769–77.

Witnessing the Witnesses: Pitfalls and potentials of the Witness Seminar in twentieth century medicine
By E M Tansey. In: Doel R, Soderqvist T. (eds) (2006) *Writing Recent Science: The historiography of contemporary science, technology and medicine***.** London: Routledge, 260–78.

INTRODUCTION

From the first experimental applications of X-rays to diagnostic and therapeutic methods around 1900 to the development of sophisticated imaging technologies and the use of lasers and other products of physics and engineering towards the end of the century, physics transformed medicine in fundamental ways over the course of the twentieth century. The application of physical methods and technologies to medicine led to the emergence of new medical institutions, the creation of new professional specialisms, the development of new forms of patient and practitioner experience and interaction and major advances in diagnosis and therapy for many conditions and diseases. Applied physics underlies much of today's technological medicine.

Though physical phenomena such as magnetism and electricity had long been applied in medicine, the new radiation physics of the early twentieth century – exemplified by X-rays and radioactivity – offered powerful new noninvasive methods for medical applications. Physicists and medical practitioners quickly began to specialize in these new techniques in hospitals and medical research institutions. Working to quantify and standardize the new techniques, these specialists quickly carved a niche for themselves in medical practice as the utility of the new techniques became apparent and as new and more powerful devices (such as larger and more powerful X-ray machines for cancer therapy) were developed, usually in conjunction with universities and industry. Alongside radiographers and radiologists, physicists began to find a place in hospitals, both overseeing the new technologies and, increasingly, in planning their use in diagnosis and in treatment.

The emergence of medical physicists and the increase in their numbers – from a handful of pioneers at a few leading hospitals in the 1910s to early 1930s to practitioners all over the UK in the later 1930s – marked the birth of a new profession. When the Hospital Physicists' Association was formed in 1943, with 53 founder members, it provided a space for the exchange of information on the introduction of new techniques into clinical practice and the development and planning of treatments, for the creation of working standards and standardized devices and the production of quantitative and reproducible results, and for dealing with legal, regulatory and professional issues. With other national professional associations and international organizations such as the International Commission on Radiation Units and Measurements, medical physics became a recognized profession.

After the Second World War, with its astonishing developments in nuclear and electronic science and technology, another set of new materials and practices found application in medicine. Heralded as the 'medical atom,' isotopes from nuclear reactors underpinned new forms of radiation therapy and the development of the new specialism of nuclear medicine. Alongside the growth of the new National Health Service, the postwar boom in physics – largely due to the Cold War and lavish government funding for the physical sciences – also had very beneficial consequences for medicine. In the 1950s particle accelerators and other technologies allowed the exploitation of ever-more powerful and selective forms of radiation in medical contexts, while developments in electronics, computing and information processing revolutionized medical technology and its diagnostic potential in the 1960s and 1970s through the management of images in techniques such as computed tomographic scanning. In the last two decades of the century, yet more forms of radiation found uses in medicine, with positron emission tomography, lasers and ultrasound and magnetic resonance imaging techniques becoming standard elements of the clinician's armoury.

This extensive and hugely productive transfer of technology from physics to medicine over the course of the twentieth century relied on mediation by specialist practitioners – the medical physicists and associated professionals. Working mainly in hospitals but liaising closely with universities and industry, medical physicists were responsible for the experimental applications of new technologies and for their subsequent routinization in medical practice. They were involved in the development and dissemination of new forms of diagnosis and treatment, the standardization of dosages and instrumentation, and in radiation protection for practitioners and patients. They were technological and institutional innovators, laying the foundations for the sophisticated scientific medicine we take for granted today. And all these developments of course changed not just the technological infrastructure of medicine and its diagnostic and therapeutic capacities, but also the experiences of medics and patients. Medical practitioners came to rely on medical physicists' expertise in administering and interpreting radiation's technological gaze, while patients and practitioners alike became familiar (if not always entirely comfortable) with large-scale complex machinery and radiation hazards as part of the twentieth-century medical experience.

Given the enormous significance of this cadre in the development of medicine over the last century, it is remarkable how little has been written about medical physicists, their work and its consequences. How and why did people make their careers in this field, and how did the work of the pioneers and later generations shape the wider profession of medical physics? How were medical physicists trained, and how did their professional self-identity emerge and change over time? How did they negotiate and mediate relations between academia, healthcare services, governmental institutions, regulatory bodies and industry? What role did professional associations, conferences, journals, funding agencies and other organizations play in disseminating and standardizing good practice and in establishing professional standards and values in local, regional, national and international contexts? In what ways – formal and informal, innovative and routine – did medical physicists contribute to the development of medical technology? And how did they relate to other scientific specialists, medical practitioners and patients across changing institutional and technical contexts?

These were among the key questions prompting the organization of this Wellcome Trust Witness Seminar devoted to the 'Development of Physics Applied to Medicine in the UK, 1945–1990.' Established in 1990 by Tilli Tansey, the Witness Seminar series has been an invaluable medium for documenting the memories of key practitioners in many fields of twentieth-century medicine. Bringing together many of those involved in the postwar development of medical physics, this Witness Seminar joins its predecessors in forming an indispensable resource for the study of modern medical history. Those present on the day as mere observers could hardly fail to be struck by the sheer enthusiasm and engagement of the participants. As they recalled their early work at the experimental frontier and the forces that shaped their careers, a palpable sense of excitement and camaraderie permeated the proceedings. The spontaneous and often humorous exchange of ideas and memories and the informal interplay of questions and answers have produced a fascinating series of insights into the development of medical physics and twentieth-century medicine more generally, and a documentary record which will be invaluable to future historians.

Jeff Hughes
Centre for the History of Science, Technology and Medicine,
and Wellcome Unit, University of Manchester

DEVELOPMENT OF PHYSICS APPLIED TO MEDICINE IN THE UK, 1945–1990

The transcript of a Witness Seminar held by the Wellcome Trust Centre for the History of Medicine at UCL, London, on 5 July 2005

Edited by D A Christie and E M Tansey

DEVELOPMENT OF PHYSICS APPLIED TO MEDICINE IN THE UK, 1945–1990

Participants

Mr Tom Ashton
Dr Barry Barber
Professor Roland Blackwell
Dr Joseph Blau
Professor Sir Christopher Booth
Professor Terence Burlin
Mr J E (Bob) Burns
Professor John Clifton
Dr Philip Dendy
Professor Jack Fowler
Dr Jean Guy
Mr John Haggith
Dr John Haybittle
Dr Alan Jennings
Dr John Law
Professor John Mallard
Professor Joe McKie
Mr David J Murnaghan
Professor Angela Newing
Dr Sidney Osborn
Professor Rod Smallwood
Dr Adrian Thomas
Dr Peter Tothill
Mr Theodore Tulley
Professor Peter Wells
Professor John West
Mr John Wilkinson
Professor Peter Williams (Chair)

Among those attending the meeting: Professor David Delpy, Dr Paul Danielsen, Dr Jeff Hughes, Dr Carsten Timmermann, Professor Andy Warwick

Apologies include: Professor Jack Boag, Professor Keith Boddy, Professor Francis Duck, Professor John Greening, Mr Clifford Gregory[†], Professor Dennis Hill[‡], Professor Norman Kember, Dr Lloyd Kemp, Dr Richard Mould, Mr G M Owen, Dr John Perry, Professor Osmund Reynolds, Dr Geoffrey Rivett, Professor Sir Joseph Rotblat*, Dr Norman Slark, Professor Tom Treasure, Dr F Peter Woodhead, Professor Heinz Wolf

[†] Died 25 February 2006

[‡] Died 10 September 2005

[*] Died 31 August 2005

Figure 1: Participants, Witness Seminar on the Development of Physics Applied to Medicine in the UK, 1945–90: From left to right. Front row seated: J Mallard, S Osborn, J Haybittle, J Fowler, J McKie, A Newing, B Barber. First row standing: T Burlin, J Clifton, J Blau, P Tothill, J Law, J Haggith, T Ashton, J Guy, J Wilkinson, D Delpy, C Booth, P Dendy, D Murnaghan, T Tulley. Second row standing: J West, R Smallwood, R Blackwell, P Williams, A Thomas, P Wells, A Jennings, J Burns.

Dr Tilli Tansey: The purpose of these Witness Seminars is to record what happened, how things happened, why they happened the way they did, the successes, the failures, the personalities involved, who did things when, where and why. This is part of the contribution that the History of Twentieth Century Medicine Group wants to make to the study of recent and contemporary medicine and medical sciences. We are funded by the Wellcome Trust, and it is very much part of their agenda for outreach and to encourage interaction between scientists, clinicians and historians. These meetings are recorded and we want everyone to contribute, put in their thoughts, their reminiscences, their disagreements. All our meetings are freely available on the web, and can be downloaded free of charge. The website address is on all our publications and we would be happy to help you further if you want information on that.[1]

The suggestion for this Witness Seminar on the development of physics applied to medicine came from John Clifton, and he has worked very closely with my

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[1] Published Witness Seminar transcripts are freely available from our website in PDF format, following the links to Publications from www.ucl.ac.uk/histmed.

colleague, Daphne Christie, in setting up this meeting. We are delighted that Peter Williams has come to chair this and so without further ado, I'll hand over to Peter.

Professor Peter Williams: I would like to add my welcome to everybody to this afternoon's meeting, which as you have heard is planned as extended conversation rather than a formal scientific meeting. When I was first approached and asked if I would like to participate in the meeting, I thought it was probably because of my current role as President of the Institute of Physics and Engineering in Medicine (IPEM), which most of you will remember as the HPA (Hospital Physicists' Association),[2] but now that's being used by the NRPB (National Radiological Protection Board), which has the Health Protection Agency.[3] Anyway, I think those terms can be used interchangeably in this company: HPA, IPSM, IPEMB and whatever you prefer. We will know what you all mean. But having started thinking that my role was as President of the Institute, I looked around and realized that I am probably one of the oldest and longest-serving people who are still in current practice. There are one or two of us around, but not a lot of people in practice who have been in the business longer than me. So perhaps I have some of these memories that need dragging out and, looking round, I am quite sure there are a lot more memories of what happened and why it happened in the group of people who have come together today.

One thing that we all have in common, apart from our scientific interest in the application of physics and engineering in medicine, is that we have been privileged, very privileged I think, to have either worked with or been trained by the people who invented the profession of medical physics. The next generation won't be able to say that. So I think now is the time to capture the memories of people who had that privilege of working with the founding members. The scientific work of our profession is recorded quite well in the archival peer-reviewed journals, and our Institute runs some of those and is pleased to contribute to other professional bodies that have journals as well.[4]

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[2] Hospital Physicists' Association (1962); Haggith (ed.) (1983); Mallard (1994). See also www.hpa-msf.org.uk/ (visited 12 April 2006) and *IPEM Heritage,* Appendix to *SCOPE* (September 2006).

[3] The National Radiological Protection Board set up by the Radiological Protection Act in 1970 as an independent statutory body.

[4] See, for example, Professor Peter Williams wrote: 'The British Institute of Radiology (BIR), The Institute of Physics (IoP), The European Society for Therapeutic Radiology and Oncology (ESTRO), European Federation of Medical Physicists (EFOMP).' E-mail to Dr Daphne Christie, 19 September 2006.

But what the scientific journals don't record is how the work got done, what the motivation was for it, the personalities involved and how they interacted; that's not as well documented at all.

The other aspect of our professional work that isn't recorded particularly well, I think, is how the work that got into the archival journals has affected clinical practice, medical practice and medical outcomes for society and for patients, who are subsections of that society. Last month the IPEM did something for the first time, we inaugurated an eponymous lecture in the name of John Mallard, and it is nice to see John here. That was held at the UK Radiological Congress about a month ago, and Peter Sharp,[5] who gave a brilliant lecture, finished off by pointing out that the outcome in research in medical physics that should be measured isn't necessarily the number of papers, or the number of millions of pounds of grants we can get. The outcome that should be measured is how our work has changed clinical practice in the hospitals and elsewhere.[6] And so I think this afternoon might be an opportunity to reflect a little bit, not just on the work that was done, but what that work produced in terms of useful outputs in the health service, which has been propagated around the world.

So with those few introductory comments, a few people have been asked if they would say a few words about various areas of the programme, and the first person that's going to kick it off for us is Alan Jennings, whom most people, I think probably everybody, will remember for his contribution at the National Physical Laboratory (NPL).[7] When I first came across Alan he was superintendent of the Division of Radiation Science and Acoustics, which is probably called something else now.[8] Alan is going to start off a part of the conversation about the early pioneering work in medical physics before the Second World War.

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[5] For biographical note see page 120.

[6] The UK Radiological Congress was held in Manchester from 6–8 June, 2005. See www.srp-uk.org/medicine/mrep050606.pdf (visited 12 April 2006).

[7] Dr Alan Jennings was Head of Radiation Dosimetry (1967–75) and Head of the Division of Radiation Science and Acoustics (1975–83), National Physical Laboratory. The National Physical Laboratory was founded in 1900 to promote links between science and commerce. See www.npl.co.uk/about/100_years/ (visited 22 March 2006). See also Pyatt (1984); Smith (1975).

[8] Dr Alan Jennings wrote: 'This is now part of the "Quality of Life Division".' Letter to Dr Daphne Christie, 22 June 2006.

Figure 2: Professor Sidney Russ (1879–1963).

Dr Alan Jennings: Strictly speaking, this Seminar covers the postwar period, but the story of the profession of hospital physicist would not be complete without giving an overview of the period before and during the war. The whole profession was established then.

At the beginning of the century there was a dual purpose for establishing the profession.[9] One was the question of teaching physics in medical schools and the other was the measurement of ionizing radiations following the discovery of X-rays and radioactivity.[10] The earliest appointments in medical schools were Lloyd Hopwood at Bart's and James Brinkworth at St Thomas', both in 1906.[11] There had, of course, been lectures by physicists and doctors before then – Neil Arnott and even Michael Faraday gave talks to doctors in the nineteeth century.[12]

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[9] See Jennings (2004).

[10] The discovery of X-rays by the physicist Professor Wilhelm Conrad Röntgen in Germany in 1895 and of radioactivity by Antoine-Henri Becquerel in France in 1896 was rapidly followed by the application of ionizing radiations to the diagnosis and treatment of disease; see Mould (1993). For biographical notes see pages 110 and 119.

[11] F L Hopwood was appointed demonstrator in physics at St Bartholomew's Hospital Medical School, London, in 1906, and J H Brinkworth to a similar post at St Thomas' Medical School, London, in 1907. See Jennings (1995).

[12] Duck (1994); Lenihan (1994).

But the first honorary physicist to a hospital was Major C E S Phillips at the Royal Cancer Hospital [the Cancer Hospital (Free)] in 1911.[13] He was 'honorary' because he apparently didn't need the money. The first paid appointment to a hospital was Sidney Russ at the Middlesex in 1913 and he had, in fact, been there since 1910 in a research post (see Figure 2).[14] By 1932, according to Eric Roberts' book, *Meandering in Medical Physics,* there were around 12 posts.[15] By the time of the war there were somewhere between 35 and 40 posts. The 1920s and 1930s were noted for the development of physics and engineering as applied to medicine. For example, higher voltages were needed to get more penetrating radiations, up to the one million volt (1 MV) Cockroft/Walton generator which was installed in Bart's by George Innes and Raymond Quick.[16]

A major activity for physicists was the measurement of X-rays and radioactivity at both radiotherapy and protection levels. The UK was pre-eminent in this field. A Committee on Röntgen Measurement and Dosage had been established in 1913. This led to the BCRU (British Committee on Radiation Units and Measurements), and to the ICRU (International Commission on Radiation Units and Measurements) in 1925.[17] Also, the British X-ray Protection

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[13] The Royal Marsden was founded as the Free Cancer Hospital in 1851 by Dr William Marsden at 1 Cannon Row, Westminster. The hospital moved to its new site on Fulham Road, Chelsea, in 1862. The hospital was granted its Royal Charter of Incorporation by King George V in 1910 and became known as 'The Cancer Hospital (Free)'. This was subsequently changed by King Edward VIII to include the word 'Royal' and in 1954 the hospital was renamed the Royal Marsden Hospital in recognition of the vision and commitment of its founder. When the National Health Service was formed in 1948 the Royal Marsden became a postgraduate teaching hospital and in response to the need to expand to treat more patients and train more doctors, a second hospital in Sutton, Surrey, was opened in 1962. See Institute of Cancer Research: Royal Cancer Hospital (1951).

[14] For biographical note see page 120.

[15] Roberts (1999).

[16] The pioneering supervoltage radiotherapy machines began to be installed just before the Second World War. Notable among these were the Medical Research Council's 500 kV van de Graaff generator at Hammersmith Hospital for research and the 1 MV generator at St Bartholomew's Hospital for treatment, both built by the staff of Metropolitan Vickers Company. In 1943, with the exception of the above, medical X-ray in the UK was carried out with 200–250 kV machines. See Phillips and Innes (1938); Schulz (1975); and 'Moving beyond the Kilovoltage era' at www.xray.hmc.psu.edu/rci/ss9/ss9_7.html (visited 23 March 2006).

[17] The International Commission on Radiation Units and Measurements (ICRU) was established in 1925 by the International Congress of Radiology. See www.icru.org/ (visited 22 March 2006).

Committee was set up in 1921, which later led to the ICRP (International Commission on Radiological Protection) in 1928.[18] Sidney Russ was a leading figure in both those organizations. The period was noted for bringing together physics, medicine and biology, and for collaboration between physicists and clinicians, and university connections.

The NPL had an important role to play.[19] It acquired its first radium standard in 1913, made by Madame Curie, in terms of mass.[20] When the röntgen, the unit of dosage, was defined in 1928,[21] the X-ray primary standards were set up at NPL to provide calibration services to hospitals, initially for pastilles, and later for Victoreens, Hammer, Philips and Siemens dosemeters.[22] The NPL also inspected departments for protection measures and provided a route for physicists into the profession. For example, Tom [Thomas] Chalmers, Jim [James] Clarkson, Harold Cook, Denis Jones and John Greening all worked at the NPL before they became hospital physicists. Years later, in the 1960s, three of us went from the hospital world to the NPL – namely Bob Burns, Lloyd Kemp and myself. Radon extraction plants were set up around the country to provide an alternative to radium for implants.[23]

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[18] The International Commission on Radiological Protection (ICRP) was founded in 1928 by the International Society of Radiology (ISR, the professional society of radiologist physicians), then called the International X-ray and Radium Protection Committee. See Taylor (2002).

[19] Smith (1975).

[20] One curie of radium weighs approximately 1 g. See Glossary, page 125.

[21] The röntgen (R), redefined in 1937, was accepted as the unit of radiation quantity. For gamma ray therapy the 'Manchester' dosage system [Meredith (1947)] provided a means for using radium (or radon) sources to give known and 'uniform' doses. By 1943 it had already been in successful clinical use. See Röntgen (1895); Spiers (1971): 258, http://ej.iop.org/links/r1xtyZWPx/dKP3GcVS2xGT5YG3av5vpA/pev6i5p257.pdf (visited 3 October 2006); Berry (1987). See also Glossary, page 128.

[22] Mr Bob Burns wrote: 'The Victoreen Condenser r-meter was a portable radiation dosemeter, manufactured by The Victoreen Instrument Co. in the USA, and widely used in the UK (and throughout the world) from the early 1930s until the 1950s, when it was superseded by the Baldwin–Farmer dosemeter.' Letter to Dr Daphne Christie, 1 December 2005. The pastille was a small plastic disc about 8 mm in diameter covered with crystalline barium platinocyanide. These crystals were bright green in colour but took on a brown coloration when exposed to X-rays. The depth of coloration was measured against a series of pieces of tinted glass and the tints were expressed in terms of fractions of 1 B, which corresponded to one erythema dose. The pastilles returned to their normal colour when exposed to daylight. The pastilles continued to be used as late as 1945. See Roberts (1999).

[23] See Jennings and Russ (1948).

Just to mention a few of the pioneers – Herbert Parker, who with Ralston Paterson between 1934 and 1938 devised the well-known distribution rules and dosage tables for brachytherapy.[24] Others included Val Mayneord, who is credited with developments in dosimetry and depth dose data, Bill (F W) Spiers, Harold Gray, Len Grimmett, Jack Meredith, Harold Miller and Frank Farmer, who became well known after the war, but were working in hospitals before the war.[25]

Williams: That's an interesting excursion through the names of people and things that went on. Rod, have you got something to say?

Professor Rod Smallwood: Just to add to that early list of names. In 1914, Sir Ernest Marsden of 'Geiger and Marsden fame' was appointed the radium curator in the physics department in the University of Sheffield.[26] The radium curator was in the physics department in the University until sometime during the 1930s, when the physics department decided that this wasn't the job of a university, to look after radium. Marsden, I think, lasted about nine months, because he was offered a chair back home in New Zealand, in, I think, the University of Wellington. The Radium Committee voted him £60 to cover setting up his new laboratory in New Zealand and thank him for his efforts in Sheffield.

Williams: It is interesting that Alan mentioned Jack Meredith as one of the people who were working before the war. Jack Meredith died about ten years ago, but certainly John Wilkinson and I knew him reasonably well.[27] He claimed to have got into medical physics by accident, because someone who was appointed to the post that he eventually took, decided to do his research in Oxford, and [he asked] would it be all right if they just sent the salary to him there? So Jack Meredith, who was an assistant at the time, was rapidly promoted and made a major name for himself.[28]

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[24] See, for example, Paterson and Parker (1934, 1936, 1938) and Glossary, page 125.

[25] Dr Peter Tothill wrote: 'Ray Oliver and I also worked at the NPL before going into medical physics.' Letter to Dr Daphne Christie, 11 February 2006. See Mayneord and Lamerton (1941); Meredith (ed.) (1947). For biographical notes see page 116 (Lamerton), 117 (Mayneord) and 121 (Spiers).

[26] Sir Ernest Marsden and Hans Geiger investigated the backwards scattering of alpha particles from a metal foil: the 'Rutherford scattering experiment' also known as the 'Geiger–Marsden experiment'. See Geiger and Marsden (1909); Rutherford (1911).

[27] Jack Meredith (b. 1913), see page 117.

[28] See, for example, Meredith (1984).

Professor Angela Newing: I wanted to tell you about Eric Roberts, who was mentioned just now by Alan Jennings. We had the great pleasure of seeing Eric Roberts in Gloucestershire after his retirement, I think his second retirement, when he came to Tewkesbury to live near his daughter in the mid-1980s. He used to attend our departmental seminars and entertain us with many interesting stories. Eric was very proud of the fact that he was born in the year that Röntgen won the Nobel Prize for Physics,[29] and he – I am talking about Eric – had worked under Val Mayneord at the Royal Cancer Hospital[30] and he had some fantastic stories to tell us. One that I remember particularly was that during the war, Eric was the youngest person in the department, whose job it was to make sure that the radium was safe when there was an air raid. When the siren went it was his job to rush along the corridor with the radium, drop it down a borehole, and then it had to be recovered afterwards. He was an absolute fund of stories and I was really very sorry when he got too ill and old to attend our departmental seminars any more. But he was a real giant of medical physics.

Mr David Murnaghan: I would like to mention John Joly who did work on the physics of radium related to medicine in the early part of the century, and who, working with Dr Walter Clegg Stevenson, developed the Dublin method in radiotherapy, which involved putting radon capillaries into serum needles for insertion into the body.[31] The other thing about the Dublin method is the great debt to the Guinness Brewery and to Lord Iveagh, who provided much of the money for the purchase of the radium. On top of that, after the First World War, they got more radium on the basis of Stevenson's work as a member of the Medical Corps in the British Army during the war. Some of the radium that had been put aside for illuminating gun sights was diverted to Dublin for

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[29] In 1901 Wilhelm Conrad Röntgen won the Nobel Prize for Physics for his discovery of X-rays. See http://nobelprize.org/nobel_prizes/physics/laureates/1901/rontgen-bio.html (visited 5 September 2006). For biographical note see page 119.

[30] Dr Alan Jennings wrote: 'Eric Roberts began work at the Royal Cancer Hospital under Mayneord and then transferred to the Middlesex Hospital under Russ. Mayneord remained at the Royal Cancer Hospital.' Letter to Dr Daphne Christie, 30 December 2005.

[31] The larger radiotherapy departments usually had about 1 g (1 curie, 37 gigabecquerels) of radium, sealed in hollow platinum needles and tubes, with contents between 1 and 20 mg. These needles and tubes were used to cover brachytherapy: interstitial, intracavitary and surface moulds. See Stevenson (1914).

the Irish Radium Institute.[32] Also, the Irish Radium Institute, established by the Royal Dublin Society, was contemporary with the Holt Radium Institute in Manchester – both founded in 1914.[33] Interestingly enough, a need for radiation protection was seen in the 1920s and a very subtle way of dealing with it was introduced. Final year students in medicine or in science could apply for an Exhibition, which paid £50 per annum, a lot of money in those days. They were limited to one year's work, which involved literally pumping off the radon gas into the capillaries.[34] So there was a start of radiation protection by limiting their working time with the radium.

Dr Sidney Osborn: I went to University College Hospital (UCH) in 1943, but I was not the first physicist there. There was one who is very little known. He was appointed to UCH in the 1930s; his job, his sole job officially as physicist was: (a) to calibrate the therapy machines once a week, and (b) to look after the radium. He decided not to spend the rest of his time on physics, but became a medical student and qualified in medicine while he was doing this. Unfortunately, shortly after the war started, the teaching unit at UCH was evacuated to Leavesdon and he was killed in a car crash soon afterwards. I am sorry he is so little known. I don't even know his name.[35]

Williams: Quite a few people have mentioned the role of physicists in looking after radium sources. Has anyone got any views about the kind of responsibility at that time, because I wasn't there obviously, but I suspect that there were things done with the radium sources that we wouldn't even dare think about now?

Mr Tom Ashton: We mentioned Jack Meredith and radon, and my recollection is that Jack told me that during the war he was responsible for moving it to the

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[32] See Joly (1995). Mr David Murnaghan wrote: 'John Joly wrote that history in the 1930s but it was reproduced in *A Century of Medical Radiation in Ireland*, which was published in 1995 by the permission of the Royal Dublin Society. "1995" refers to the publication date of this Faculty of Radiologists' book. The original publication of the history is not readily accessible today.' Letter to Dr Daphne Christie, 16 June 2006.

[33] Magnello (2001): 23–34.

[34] See, for example, Jennings and Russ (1948); Spear (1953 b).

[35] Professor John Clifton wrote: 'The first full-time medical physicist at UCH, London, was Rees in 1931; part-time (1932–40), followed by F T Farmer (part-time, 1940–1), S B Osborn (part-time, 1941–3; full-time, 1943–64) and J S Clifton (1964–).' Note on draft transcript, 13 July 2006.

Blue John mines in Derbyshire, along with the radium, where it was kept safe until the end of the war. I think that was true.

Williams: I think that is true and they also carried on using it and producing radon. I think Kenneth [Sydney Kenneth] Stephenson was also involved in that.

Dr Barry Barber: The story at the Royal London Hospital was that at the beginning of the war, it was decided that the 1.5 g of radium in the radon plant needed to be dealt with and put down a borehole, and the technician there, Ted Coles, was instructed to evaporate it down, which we understand was done in an open kidney dish, and it was then put down in a borehole. Later on, it was retrieved and set up at, I think, Barton-in-the-Clay, Bedfordshire. Alan Jennings knows more about that than I do. But they continued producing glass radon seeds for a long period there,[36] under very difficult conditions, and once the Radiochemical Centre was set up in 1948, Ted Coles and his colleague [Wally Hartnell] were too badly damaged to be taken on by the Radiochemical Centre.

Dr Adrian Thomas: I met Val Mayneord a couple of times towards the end of his life.[37] I think it is interesting to look at the origins of hospital physics or medical physics. Obviously, the earlier group are pure physicists, people like Professor Silvanus Thompson, who became involved in X-ray work.[38] It is interesting reading some of Val Mayneord's comments, saying that often there was a certain amount of tension or difficulty between the hospital or the medical physicists, and the physics community generally, who may not have thought so much of those specializing in medical physics, and saying that one often got more support from the medical staff, from the doctors, than from the pure physicists.[39]

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[36] Spicer (1946). Radium chloride was held in carefully shielded solutions: from this, radon gas was milked off each day into fine glass capillary tubes, which were then cut off into 1 cm lengths. These were then enclosed in thin platinum sheaths to become 'radon seeds'. With the short half-life of radon, seed implants could be left *in situ* within the body permanently. See also Jennings and Russ (1948).

[37] Professor Val Mayneord (1902–88), see page 117.

[38] See Thompson and Thompson (1920).

[39] See page 80.

Murnaghan: I recall a nice picture in, I think, the Imperial War Museum. One of the boreholes, used to store the radium safely during the Blitz, was damaged when the hospital was bombed, and collapsed on the borehole. I think it was the NPL and that it was E E Smith and Walter Binks who were involved in finding it eventually, with the assistance of the Civil Defence, using a very simple gold leaf electroscope type of instrument.[40]

Professor Terence Burlin: I didn't function before the war, but I do have memories of some of those who did. I was appointed to the Mount Vernon Hospital when Hal Gray was there and Jack Boag. I recall how you heard a resonant laugh along the corridors, when Gray arrived.[41] My memory was how much consideration and time they would give to me as a very young man who had questions, and they would listen and explain. There was then a neutron generator, which had been used for earlier radiobiological experiments, still in existence there. My surprise was that they survived electrocution when they scraped along past the woodwork to try to get to the controls and set up their experiments. I also recall Eric Roberts, who was my supervisor and gave me advice, but there was one thing he did that I particularly remember: I used to describe the results of my experiments, by writing, 'It is interesting to note that', and Roberts always used to cross this out and said: 'It may be to you, but it doesn't follow that it is to anybody else. Delete.'

Professor John Mallard: You have all been talking about boreholes in which to put the radium down during the war. Aberdeen had a very unique one. Harry Griffith was the physicist responsible for the radium during that time and he built a wooden hut at the bottom of the quarry from which all the granite originated that built Aberdeen at the beginning of the century. It was 400 feet deep and was constantly pumped out to keep it free from water. You had a hell of a job getting it up and down 400 feet, of course.

Williams: There is a myth that Aberdeen rock is so radioactive, they use radium to shield against it.

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[40] The picture was reproduced on the cover of the September 1983 issue of the *HPA Bulletin.* See Figure 3. Professor Angela Newing was Editor of the *HPA Bulletin* at the time leading up to its 40th Anniversary.

[41] For biographical notes see pages 110 (Boag) and 113–4 (Gray). For a history of the Gray Cancer Institute see www.graylab.ac.uk/about_us/index.htm (visited 23 March 2006).

Figure 3: Front cover of the *HPA Bulletin,* September 1983 issue celebrating its 40th Anniversary. See page 13 and note 40.

The other thought I had when Alan [Jennings] was talking about the evolution of the NPL as a place where radiation was measured, was that the early physicists in the hospitals didn't bother with the NPL, they calibrated their machines by irradiating their own arms. There was quite a lot of work done where people were sacrificing themselves and taking enormous risks, as we see it today, in trying to establish what the erythema dose was.[42]

Jennings: I think you were talking earlier about soft X-rays, erythema dose to the skin.

Mr John Haggith: I am always struck by how isolated the few physicists were who worked in the dozen or so centres, outside London, dotted around the UK

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[42] The 'mean erythema dose' was defined roughly as 'the amount of radiation which will just produce a mild erythema on the average patient'. The NPL suggestion was that 1/1000 of the skin erythema dose might safely be received by the whole body if the radiation was spread over five days [see Spear (1953 b)*:* 8]. Later, when there was agreement on the value of the erythema dose in R (röntgen), this was interpreted as 0.2 R per day or 1 R per week and adopted by the International Committee set up by the International Congress of Radiology in 1925. This dose level was called the tolerance dose rate (approximately 10^{-5} R s^{-1} for a 35-hour week) and this concept and level held until after the Second World War, although the American Committee on Protection used a lower level of 0.1 R per day.

at the time that the HPA was formed in 1943. Griffith, up in Aberdeen, was the only physicist north of Edinburgh and Glasgow and, incidentally, he even provided radon seeds down to Newcastle. When I was tracing founder members in the course of compiling the history of the HPA[43] I received a letter from John Munson, who was the physicist in Bristol in 1943. He said that at that time he was the sole physicist south-west of the line between Birmingham and London and that he used to trundle his Victoreen dosemeter round all the south-western counties – Devon, Cornwall, Dorset, Somerset, Gloucester and South Wales – in his ancient Austin Seven, measuring radium and looking at protection.

Williams: There was an observation made [by Adrian Thomas] about the fact that physicists working in hospitals were perhaps looked down on by the pure physics community and found a more natural home inside the medical schools. Do you think that was a general view at that time?

Professor Peter Wells: Just following up that comment about Munson, because it relates to the point that you were making. The first physicist working in the Bristol hospitals was Dr Norman Thompson, who was in the physics department of the university, and he used to go down to the hospital – it was long before my time – for a day or half a day a week, just to help out with the radiotherapy. So in the very, very early days the physicists in the universities were the ones who actually did the work, I imagine. I am also curious – perhaps people can remember, or tell me – what the professors of physics in the London teaching hospitals, for example, did. Did they simply teach physics of the A-level kind that we remember, or did they involve themselves in radiotherapy and diagnostic radiology in those days?

Mr Bob Burns: In 1928 a book was published by a radiologist, Bernard Leggett, referring to the physics staff required by a radiology department, and it stated:

> The physicists should in all cases be subordinate to the medical officers. The young physicist–engineer of X-ray manufacturers' test rooms will be found more useful than the purely theoretical, highly-paid academic physicist. Such a commercially trained physicist will be found usually to have an extended theoretical knowledge as well as considerable practical experience and having been used to receiving orders, will be

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[43] See Haggith (1983): 83–138.

> more amenable to carrying out the work required by the medical staff than the theoretical physicist, who often tends to be very superior to the purely medical radiologist.[44]

Before I went into medical physics in 1953 I spoke to two people about the work. One was Alan Jennings and the other was Eric Roberts. I mainly went to see Professor Roberts, because he was very influential at the time, and I wondered whether he knew of any job that might be available.[45] He chatted to me about the duties of a medical physicist and he said that there wasn't really such a thing as medical or hospital physicist. There was a physicist working in a hospital, but he was just a physicist; he could do anything in the hospital, but he wasn't a medical or hospital physicist. Now contrast that with Ralston Paterson, a radiotherapist. He wrote a book round about that time or a little later, and in it he stressed the importance of the physicist who worked closely with a radiotherapist:

> The team, even for the smallest department, consists of a radiotherapist and a physicist. Such a radiotherapy physicist is just as essential a member of the team as the therapist himself.[46]

In my early days as a hospital physicist, I was amazed at the number of radiotherapists I met who were trained by Paterson. They seemed to be everywhere, and they always stressed how important the physicist was. So there you had a dichotomy of views between Ralston Paterson and Eric Roberts.

I experienced both. It wasn't until I went to Westminster Hospital, that I managed to get that rapport with radiotherapists, and in the treatment of individual patients, the physicist and the radiotherapist worked together. I became convinced that Eric Roberts wasn't right. There were such people as 'medical physicists' who had acquired some knowledge of anatomy and medical terminology and who were willing to collaborate with therapists or other clinicians in the treatment or diagnosis of individual patients.

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[44] Leggett (1928)*:* 477. Mr Bob Burns wrote: 'This may be thinly veiled criticism of Sidney Russ, who was Professor of Physics at the Middlesex Hospital Medical School, London, when Leggett was the radiologist at the Middlesex Hospital.' Letter to Dr Daphne Christie, 1 December 2005.

[45] Mr Bob Burns wrote: 'He [Roberts] had succeeded Professor Russ at the Middlesex Hospital in 1946.' Letter to Dr Daphne Christie, 1 December 2005.

[46] See Paterson (1963)*:* 527.

Williams: I think that dichotomy is still being discussed. Many of the current senior people in the profession ask the question whether we are medical physicists, or physicists working in medicine. I think we are probably both. The problem with identifying yourself purely as a medical physicist is that you then practise in the bits of medicine where the role of the physicist is already established. The physicist who is working in medicine, on the other hand, is able to look out and to develop new areas that haven't been thought of yet. So, when you have an established part of the profession, radiotherapy for example, it is clear you need people skilled in radiotherapy, but where did the MR expertise come from? Not from people that knew – or they imagined they knew a lot about radiotherapy – but they were physicists who were able to apply those skills to a different area. I am not sure that those two concepts are totally incompatible.

Professor Jack Fowler: I came across this dichotomy that Bob Burns is talking about as soon as I went into hospital physics, as a radiotherapy physicist, in 1950, in Newcastle, where Frank Farmer was in charge. He was extremely keen on research, but he also taught me that the important thing is to do the work for the patients, that you have to do the radiotherapy plan first, and from this came the research questions. I never had any problem with this dichotomy. When I moved down to London I found that the senior, presumably well paid, university physicists, tended rather to look down on the hospital physicists, with the important exception of the Royal Marsden Hospital where they did both university medical physics and the regular hospital physics. When I went to Hammersmith in 1962, I ran the Medical Physics Department in that combined way. From my point of view, it was important both to do the routine work and to get a lot of satisfaction out of doing a good radiotherapy treatment plan, and also to be involved in some intellectual aspects of improving the whole subject, thinking of new techniques and developing them. It is very important that they should both go together. These days, I think, we are much better at this than they were back in the 1950s.

Ashton: I am not sure whether this fits in or not. I was at the Christie [Hospital, Manchester, 1951–5] with Jack [Meredith] and certainly there the medical staff and physicists did rub along well together, because we always had coffee in the library together. One morning one of my medical colleagues said when I went in, 'Oh, there's no cuppa for you, Tom. Just put it in the sugar basin, because Tom likes a lot of sugar.' So that was an example where I think physicists and medical staff went together.

The other thing that I would like to mention, or perhaps you all know, is that Russ in May 1958 wrote to the *British Journal of Radiology* about medical physicists and hospital physicists implying that saying that you were a medical physicist was incorrect, unless you were medically qualified.[47]

Another point is with regard to Paterson and the people that he trained. I read an article coming down in the train today about the outsourcing of research.[48] The Christie Hospital, through Brian Jones and me, provided an outsource service by calculating the treatment time for radium needle tongue implants for a radiotherapist in Portland, Oregon, who had trained at the Christie. He sent the films to us, and Brian Jones and I did the calculations and for ten shillings cabled him the treatment time. That was in 1955.

Figure 4: Professor William (Bill) Spiers (1907–93).

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[47] Russ (1958).

[48] Mr Tom Ashton wrote: 'The article I read on the train was an article in a current financial newspaper relating to business in general and I have no recollection which newspaper.' E-mail to Dr Daphne Christie, 25 June 2006.

Williams: I promise not to tell the taxman. Perhaps we ought to move on a little bit. Alan Jennings will give three or four minutes' worth of comments about the period a little bit later on, the war period.

Jennings: I think the most important step forward during the war was the formation of associations. On 8 May 1943, Bill Spiers, with others, launched the Northern Group of Hospital Physicists,[49] and on 24 September the same year Sidney Russ, with the support of three other professors, Henry Flint, Lloyd Hopwood and Gilbert Stead, launched the Hospital Physicists' Association (HPA), and this became the first national body, the first in the world.[50] The American Association of Physicists in Medicine (AAPM) didn't start until 15 years later.[51]

When the HPA was launched in 1943, it had 53 members. As far as I know, only five of those are alive today, and three are here: Sidney Osborn, Theo Tulley, and myself. Unfortunately, two others couldn't make it: Jack Boag, who is 94, and Kenneth Stephenson. So the five of us are still around. About a year ago, when this seminar was first planned, three more founder members were alive, Jim Clarkson, Frank Farmer and Clifford Walker. Two other well-known hospital physicists, Michael Day and Nigel Trott, have also died recently.[52] So we were all anxious to get on with this meeting, while we are still here.

It is interesting to look at the distribution of hospital physicists around the country. These facts come from the book *The History of the HPA 1943–83*, which John Haggith, who is here today, put together.[53] Of the 53 founder members in

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[49] Dr Alan Jennings wrote: 'The Northern Group was founded on 8 May 1943 when 11 physicists from seven hospitals met in Leeds: see Haggith (1983), note 50.' Letter to Dr Daphne Christie, 22 June 2006. Bill Spiers was its first chairman.

[50] Haggith (ed.) (1983). Dr Alan Jennings wrote: 'In 1993 the HPA decided to cut its "union" activities from its scientific endeavours, the latter becoming the Institute of Physical Sciences in Medicine (IPSM), the former retaining the name HPA. In 1995, the IPSM merged with the Biological Engineering Society (BES) to become the Institution of Physics and Engineering in Medicine and Biology (IPEMB), renamed in 1997 as the Institute of Physics and Engineering in Medicine (IPEM). With the incorporation of the Association of Medical Technologists, the joint membership approached 3000 by the year 2003.' Note on draft transcript, 30 December 2005.

[51] Adams (1978); Laughlin and Goodwin (1988). See also www.aapm.org/medical_physicist/history.asp?org=open (visited 22 March 2006).

[52] The biographies of the 53 founder members are given in Haggith (1983): 85–138.

[53] Haggith (1983).

1943, 38, that's 72 per cent, were in London, but half of those, 19, were in only three centres – seven each in the Hammersmith and the Middlesex and five at the Royal Cancer Hospital. Of the 15 outside London, only one department, the Christie with three, had more than one physicist. So there were a large number of sole physicists. Comparing those numbers with the numbers today is of interest. Since the merger of physics and engineering societies in medicine, the IPEM now has a membership of over 3000, and some departments have become very large. For example, the Royal Marsden had five physicists in 1943, and in the latest report they have 115, with 31 PhD students.[54] The HPA was very valuable, particularly for sole physicists. From 1944 to 1968, the HPA held three residential meetings each year in different locations around the country. It functioned essentially as a 'club', including an annual general meeting, plus other scientific and professional meetings.[55]

During the war, two services were run in London which warrant mentioning. They were based at the Middlesex. Sidney Russ was made responsible for the King's Fund stock of radium that was issued to radiotherapists. Other stocks were kept elsewhere in the country. He also ran the King's Fund panel of physicists which provided physicists to hospitals that didn't have full-time posts.[56] Three radon plants were set up at a safe location, as has been mentioned before, in Barton-in-the-Clay, Bedfordshire. One was set up by Sidney Russ, with his brother William Russ on site as manager. The other two were set up by the MRC and by the Royal London Hospital.

I should like to mention my own introduction to the Russ empire, because other people had similar experiences. When I was 19, I took the first part of my final exams at Imperial College and we were told we could only complete our degree in a final year if we undertook a commitment to do war work, which I understood to mean weapons research. As a Quaker, I could not accept this, so I had to leave the college, and was sent to a tribunal, who in turn sent me

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[54] Institute of Cancer Research and Royal Marsden NHS Trust. Joint Department of Physics (2004).

[55] By 1973, the HPA had close to 900 ordinary members: Earlier membership numbers: 1943, 53; 1953, 212; 1965, 521; 1973, 899, 1983–, 1175. Data provided by Dr Alan Jennings, 30 December 2005.

[56] Dr Alan Jennings wrote: 'Sidney Russ was a remarkable man, and as John Haggith writes in his book [Haggith (1983): 126] "the world of hospital physics is greatly indebted to his foresight, wisdom, enthusiasm and achievements as a pioneer". See the obituary by Windeyer (1963). Russ was precise and autocratic, but genuinely kind and understanding. See also Jennings (1998).' Note on draft transcript, 30 December 2005. For biographical note see page 120.

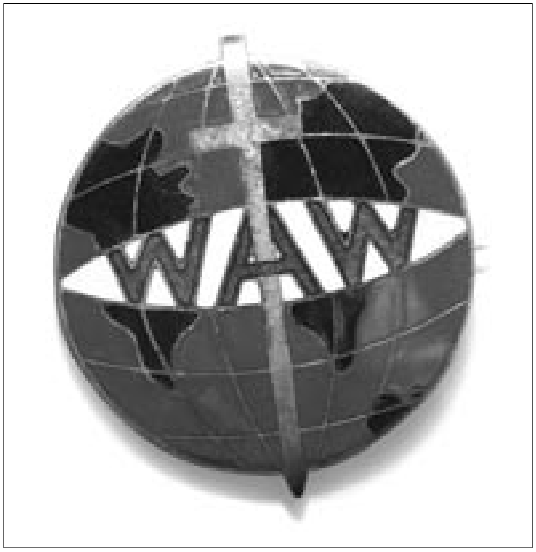

Figure 5: The badge, 'Women against War' for the organization founded by Mary Russ, wife of Professor Sidney Russ.

to Sidney Russ. Now Sidney Russ had some sympathy for the pacifist cause, because he had lost a son in the war and his wife was a campaigner. On this badge, which Mrs Russ gave to my wife, WAW, stands for Women against War, an organization that she had founded (Figure 5). I was interviewed by Russ, who paced up and down the room, with his hands behind his back, firing questions. He was a very strong personality. But I got the job.

At the Middlesex I met Frank Farmer, who showed me round the medical physics department, and then I was sent to Barton-in-the-Clay, Bedfordshire, to the radon centre, where I took over from Jack Boag, and met Frank Stewart who worked there.[57] After two years in Barton, I returned to London and joined other people, including Sidney Osborn on the King's Fund Panel.[58] We visited London hospitals, calibrating outputs, planning treatments, looking for lost radium and so on. One trained on the job and, in my case, with Clifford Walker. We learnt how to use Victoreens, how to use the Paterson–Parker tables for radium treatments and so on.[59] After two years visiting various hospitals, I was appointed to one of those that I had been visiting, the Royal Northern Hospital,

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[57] For biographical notes see pages 110 (Boag), 112–3 (Farmer) and 121 (Stewart).

[58] See the King's Fund website at www.kingsfund.org.uk/ (visited 14 June 2006).

[59] See Paterson–Parker tables, reproduced from Meredith (ed.) (1947).

and I became the sole physicist, just as Sidney Osborn was the sole physicist at UCH. In time the numbers grew, and in fact this entry to the profession via the King's Fund was used by quite a number of people.

I was disappointed, of course, to leave Imperial College, because I couldn't finish my degree. Fortunately, I was able to complete it later at Birkbeck College, part-time, and as I met my wife there – we are soon to have our diamond jubilee anniversary – I am very glad I made the break.

Williams: You started off, Alan, by talking about the formation of the HPA and people starting to work together. What difference did you think that made, people working in isolation? It must have been very difficult. What were the benefits in terms of getting things moving faster?

Murnaghan: One recollection – this was a bit later on – something that the HPA did very well, was the Diagrams and Data Scheme.[60] For those physicists who were on their own, this was an absolute godsend when you wanted to do radium calculations or treatment planning, you could get all the data for just the price of a photocopy. I think that scheme was a major help to a lot of people.

Osborn: The major advantage of having the HPA at that time was that at least we knew there were physicists working elsewhere in hospitals, we knew their names and addresses, and something of their reputations, as to what they were particularly interested in, and this helped those of us who were in single appointments at the time enormously. We were able to collaborate, informally, and it made things very much easier in many ways.

Thomas: All this was long before I was born. I gather that prior to the HPA being formed there was a meeting in 1943 – there was a Northern Hospital Physicists' Association Group and Sidney Russ had written to all the heads of departments trying to set up this new group. I think the initial idea was that this group was going to be purely scientific, and there was a certain amount of objection to this. We should also discuss technical and professional issues, such

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[60] The Diagrams and Data Scheme was initiated by the HPA to facilitate the exchange of useful diagrams and data between radiotherapy centres. Dr John Read, the first Secretary, was attached to Mount Vernon Hospital, Northwood, and the scheme remained based there as successive secretaries, D E A Jones, F S Stewart, C Gregory and J H Garrett took control until it was taken over by the IAEA in 1963. See Read (1945, 1946); Jones (1950). See also Wood (1983).

as terms and conditions of service, which obviously became quite important when the NHS was set up. So even when the HPA was set up, this northern group became quite important. I don't think from what I have read that London was as dominant as suggested.

Fowler: Yes, I remember being in the Northern HPA group and I started relatively late, in about 1950. This group felt that they were the HPA, and that the people from London had not been particularly active in getting together in this way. I am happy to say that the Northern HPA still believed that it ought to be a national organization, and they involved people like [Jim] Clarkson from the south,[61] and anyone from London who wanted to join in the very strong Northern HPA group that was already beginning to coalesce in the early 1950s.

Williams: What scientific work was done jointly within the HPA?

Burns: I will mention physicists working on their own. Some of the important work of the HPA during its early years, when I was in medical physics, was that they held meetings three times a year, and they went around hospitals. Each hospital had an open day, and these were very well attended – probably about 70 or 80 per cent of members of the HPA used to go around the country, visiting these various hospitals. Physicists working on their own gained a great deal of help from this.[62]

Barber: I am not quite sure where this fits in, but it seems to stitch in with the developments of the HPA and the comments made previously about the links with the medical fraternity.[63] One thing I found very helpful was the British Institute of Radiology, where you met the clinicians on equal terms and had a forum for discussion, which I thought was equally as valuable as the

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[61] See page 112.

[62] Mr Bob Burns wrote: 'The usual arrangement was that scientific presentations on recent developments were held on a Friday, with a communal dinner and a business meeting in the evening, and on the following Saturday morning there were visits to physics and radiotherapy departments, which otherwise would not have been open. The knowledge gained helped to compensate for the absence of any agreed job description or formal training for hospital physicists at that time.' Letter to Dr Daphne Christie, 1 December 2005.

[63] See pages 12 and 80.

HPA meetings when they came round to one's hospital.[64] I think that's another dimension, putting those things together effectively to make the whole thing work properly.

Mallard: I think we should remember that these were homemade equipment days. So visits to other hospitals were extremely valuable. You saw the way they had tackled the problem that you were trying to work on, and you went back and you modified your own homemade method, whatever it was. It was very, very important.

Williams: Extrapolating back from the period I knew about, and I guess that it wasn't just homemade equipment – small equipment, test equipment – that we all used, presumably a lot of the equipment brought in from the X-ray manufacturers was almost made as one-offs, there were no two machines exactly the same. Therefore seeing how other people did it, and what they had, was very valuable.

Haggith: I am struck by the important contribution to medical physics made by people like Alan Jennings, the conscientious objectors – there was a substantial group of those who came into hospital work during the Second World War – Professor Russ, of course, was very helpful to them. Similarly, refugees from Europe, Stefan Pelc and Gottfried Spiegler, and Joseph Rotblat, who later was awarded the Nobel Peace Prize [1995], and I am sure there were others as well [**From the floor**: Herbert Freundlich].[65]

Osborn: Your comment on the equipment reminds me that when I went to UCH to the physics department, I had no secretary, no technician. My equipment consisted of a lathe, a soldering iron, a Victoreen r-meter and a slide rule.

Dr John Haybittle: I wanted to support what Barry Barber said about the influence and use of the British Institute of Radiology for physicists, because I experienced the same, also having been a secretary of the Institute.[66] It was

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[64] For a history see www.bir.org.uk/c2/uploads/history.pdf (visited 23 March 2006). See also www.aim25.ac.uk/cgi-bin/frames/browse2?inst_id=81&coll_id=7258&expand= (visited 15 September 2006).

[65] See http://nobelprize.org/nobel_prizes/peace/laureates/1995/rotblat-lecture.html (visited 5 September 2006). For biographical notes see pages 119 (Pelc) and 121 (Spiegler).

[66] Dr John Haybittle was Honorary Secretary of the BIR from 1962 to 1967.

a very good method of getting to know radiotherapists other than those you worked with, and generally widening one's experience and feeling for the medical profession.

Mr Theodore Tulley: As a young physicist I was taken on by Val Mayneord at the Royal Cancer Hospital [Free][67] as it was then, who was willing to give a conscientious objector a beginning, and rather unusually he put me to work in the infrared. The following year he said, 'There's a meeting at the Middlesex, you had better go along', and that was the foundation of the HPA.

From then on I became aware of strange activities in a quite different field of work from what I had been involved with, and I gradually learned about this. I was soon put on to the DMR (Diploma in Medical Radiology) physics course, at least the demonstration side of it. Two or three points of history are worth noting: one was the Royal Cancer Hospital, one of about half a dozen departments in the country that had a Bryant Symons radium unit, commonly known as a 'radium bomb unit'. Five grams of radium was inserted in these things; I think they dated from the early 1930s, probably from the start of the Radium Commission in 1929.[68]

One of the points I want to mention is the importance of the Radium Commission in the introduction of physicists into hospitals. Radium centres were established, I believe, in the early 1930s, as a result of the Radium Commission's first work, and they sensed very strongly that these radium centres must have a physicist on the staff. There was another document issued by the Radium Commission, around 1937, that underlined that.[69]

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[67] After the NHS came in, the Royal Cancer Hospital (Free) became the Royal Marsden Hospital. See note 13.

[68] Telecurie units were known as 'radium bombs', or later 'cobalt bombs'. The one at the Cancer Hospital as early as 1930 consisted essentially of a cube of lead of about 15 cm on each side, mounted on something like a portable X-ray stand. Into one side of the block was cut a 5 cm square aperture towards the centre of the block. The whole of the hospital's available stock of radium needles and tubes, around 1 or 2 curies, were wired on to 5 cm plastic cards and these were packed in the bottom of the 5 cm square hole and fixed there. Thus from the 'bomb' there emerged a 5 cm square section gamma-ray beam and when the unit was in contact with the skin, the approximate source–skin distance was 5 cm. From around 1935 onwards, a new generation of telecurie bombs came into use, designed by Dr Leonard Grimmett of the Radium Institute and built by Messrs Bryant Symons. Radium sources of 5 or 10 g (curies), sealed in 5 cm diameter light-alloy cylinders, became available. Such a container was stored in a heavy lead-lined safe in the treatment room.

[69] For a history see Spear and Griffiths (1951).

But in Hull, where I landed after about half-a-dozen years at the Royal Marsden, I was to establish a physics department. I had enormous help from colleagues in Leeds, especially Bill Spiers,[70] who oversaw the work in Hull very helpfully. But the history in Hull is quite interesting as a sidelight to what was going on. Hull did not get any radium from the Radium Commission, it wasn't big enough, and it had to raise its own. It had a charitable event and established a radium trust, and there was an interested physicist, Stuart Palmer, who later became Professor in the then University College in Hull. But he, from time to time, tested the radium, audited it to make sure it was all there and straightened bent needles and so on, but didn't take a close interest in the work. As far as I have been able to tell, there is no record of any physicist from the department being delegated to work on this field, otherwise Hull might have made some progress a bit sooner.

Coming to Hull I found, therefore, a substantial stock of radium wanting attention, and a 180 kV so-called deep-therapy unit. There were plans which had been prepared under the care of Bill Spiers and John (J R) Nuttall from Leeds, for a new radiotherapy department, which was being built but hadn't started when I got there. I had a small office and was given the initial job of testing radium for leaks, generally getting it in order, and providing what help I could to the radiotherapist who had also just been appointed.[71] This was all part of the general establishment of radiotherapy centres more widely in the country, as a result of the preparation for the NHS in 1948. So again, there is an official underline to what was being done locally.

Many people have spoken of their experience working at Barton-in-the-Clay, producing radon seeds. What I remember is *receiving* radon seeds from Barton-in-the-Clay. Generally, there must have been up to about 20 millicuries, or possibly more, that arrived in a small cardboard box, measuring something like three-and-a-half inches, by two-and-a-half inches, by one inch, with a little

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[70] For biographical note see page 121.

[71] Mr Theodore Tulley wrote: 'Ken Beetham, another Ralston Paterson trainee (see Bob Burns' contribution on page 16).' E-mail to Dr Daphne Christie, 14 July 2006.

piece of lead foil wrapped round the radon seeds. It was dramatically different when we started receiving materials from the Radiochemical Centre some time later.[72]

Jennings: I should mention a story about radon seeds. When they were dispatched from Barton-in-the-Clay, they were, as you say, wrapped in a piece of lead foil. They used to be taken eight miles to Luton to post, but I think there was some trouble with films in the same postbags, so we took them to Bedford instead. The point was that the chap who took most of our radon was Clifford Walker, and when he went on his motorbike, he took several hundred millicuries on his lap to post! I should mention, for ten years or so he was unable to have any children. He was going to adopt some, but fortunately succeeded in having his own. He ended up having three or four children of his own, seven or eight grandchildren, and lots of great-grandchildren, all perfectly OK.

Thomas: To pick up on that earlier comment about the significant education and teaching role of physicists for generations of both radiologists and radiographers. In the 1980s I did the London Fellowship Course and Melvyn Myers taught us at the Hammersmith Hospital. We used books by Meredith, a book by Meredith and Massey, and in fact, prior to that I think Gilbert Stead wrote his famous book called *Elementary Physics*, which was physics without any mathematics, and does actually exist, I suppose.[73] Also the fledgling HPA was quite involved in helping the College of Radiographers to set standards and exams, and to give advice of what physics was needed for training radiographers and radiologists to perform their profession properly.

Williams: Can I make a comment about Meredith and Massey, because they were the two major figures in the department that I joined in 1969? And remember that John Massey wasn't involved with my appointment, and so I wasn't his favourite person. But when he came back from South America, the second

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[72] Mr Theodore Tulley wrote: ' "dramatically different" because such consignments were enclosed in massive lead containers and sent by rail with the requirement that we should collect them from the station! Fortunately that was less than half a mile away. The date was as soon as the service was transferred from Barton-in-the-Clay to the Radiochemical Centre.' E-mail to Dr Daphne Christie, 14 July 2006. Professor John Clifton wrote: 'For dispatch by public transport (i.e. by rail in the guards' van) this was mounted in a substantial orange painted wooden crate.' Letter to Dr Daphne Christie, 13 July 2006.

[73] Professor Gilbert Stead was a pioneer in the development of radiology as a recognized medical specialty. In 1924, he wrote *Elementary Physics*, which was hailed as a superb source of help to struggling radiology and medical students [Stead and Allsopp (1964)]. See also page 121.

edition of Meredith and Massey had just been produced, and he gave it to me to proof-read – I didn't know what proof-reading was at the time – he wanted me to check on the spelling and whether the commas were in the right place.[74] So after about a week I went back to see him and said, 'Well, I wasn't quite sure if the explanation for photoelectro effect was clear enough', and surprisingly, he didn't kick me out there and then, but it was a bit risky in retrospect.

Osborn: A comment was made about radium in use between the wars by the National Radium Commission (NRC). In about 1944 I was concerned about the condition of three radium tubes being used for brachytherapy: one nominally containing 50 mg of radium, and each of the others 25 mg. Radiation measurements showed that they each contained only about half the nominal content. Further, autoradiography showed that the radium in the tubes was loose and could be shaken from end to end of each tube. This was seen as detrimental to good radiotherapy. It turned out that after the First World War all the luminous dials used by the Services were collected together under the auspices of the National Radium Commission; the radium that they contained was recovered, remounted and reissued to hospitals for radiotherapy. I managed to gain access to the files of the NRC, and came across one entry which disturbed me. In about 1925 it was discovered that one radium tube in clinical use contained much less than its nominal content of radium. It was found that the sealing of this tube was faulty, and that its actual content was about 20 mg, not 50. The radium in all the tubes then used for clinical work was found to be radium as bromide, to facilitate manipulation during manufacture, and subsequent repair. Clearly, the body fluids of patients had been able to pass through the faulty seal, dissolve some of the radium bromide, and then leak out. No records were available to indicate which patients might have suffered as a result of this defect. However, the NRC then recalled all the radium in clinical use, converted it to sulphate (which is virtually insoluble) and the re-made needles and tubes were then returned to clinical use in such a condition that that same problem would not arise again.[75]

Williams: I often wondered how in those early days the radium sources were actually standardized. We talk now about numbers of milligrams, were they weighed out on scales, or was the ionizing radiation coming out of them

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[74] Meredith and Massey (1968).

[75] See Osborn (2004).

measured by physicists who knew what to do? Somewhere in our archives in Manchester there is a certificate from Ernest Rutherford, who measured the output of the first radium sources used.[76] Since we found that, we now just call him Ernest.

Jennings: The original standard at the NPL was in terms of mass, weighed out by Marie Curie herself. Later on, the NPL built two special chambers for measuring the standards in terms of ionization produced.

Burns: Yes, I can confirm that. I have been reading the history of radiology and radiation at NPL, and in the early days it was called 'standardization', rather than 'calibration', and the original radium source from Madame Curie was used to calibrate other radium sources, which from 1912 was then used to standardize radiation dosemeters in those days rather imprecisely. So radium was the primary standard for radiation in the UK, well before the röntgen unit was defined and the primary-standard free-air chamber was developed at the NPL in 1928.

Professor John Clifton: One final comment, perhaps to one side, because I wasn't in medical physics during the war. But it is perhaps sobering to realize that UK medical physics was in part responsible for the invention of the atomic bomb, because Leo Szilard[77] went to [Tom] Chalmers who was then at Bart's, requiring a substantial ionization source to test out a reaction theory. Chalmers and Szilard used the entire radium stock at Bart's to prove this particular experiment and led to the publication of the Szilard–Chalmers reaction, which was subsequently used to produce uranium for the atomic bomb.[78]

Williams: We have spoken about what happened and who was around before and during the war. The next topic is the expansion of the profession in the five years immediately after the war. There was a very fast expansion during that period and Sidney Osborn is going to say a few words about it.

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[76] Meredith (1960).

[77] For biographical note see pages 121–2.

[78] Professor John Clifton wrote: 'Leo Szilard in 1934 filed the first patent on a neutron chain reaction: the Szilard–Chalmers reaction. A method of concentrating artificially produced radioactive isotopes.' Note on draft transcript, 13 January 2006. Patent number CA552312, 1958-01-28.

Osborn: That was the period when the NHS came in, and this made a big difference in a number of ways.[79] Before that, some hospitals like the Royal Cancer Hospital (Free), used names that they hoped would attract donations, so that the hospitals could be kept going. They abandoned this after 1948, although, at about that time, I did talk to a hospital finance officer at one of London's wealthiest hospitals and he said that one-third of all income they received was used in advertising for more donations, so the hospital finance office was primarily an office for getting more donations in.

But there was one big change. In the planning of the NHS there was the question of qualifications and salaries. Up to then each hospital, or group of hospitals, used to pay the salaries they thought they could get away with, rather than work to any common scale. One of the things that surprised me at this time, and which led to other things, was that in around 1943 I was asked by the Director of the X-ray department [Dr S Cochrane Shanks] to measure the radiation doses routinely administered to patients in his department who had barium meal examinations. At that time, the general philosophy about the irradiation of X-ray patients was that each patient would only receive a small amount of radiation, and that any patient would receive such a dose so infrequently that any effect on that patient would have worn off by the time of the next irradiation, if any. At that time, a barium meal examination involved the administration of a barium contrast medium into the stomach, followed by an X-ray examination on a fluoroscopic shield accompanied by a few radiographs. There was, in those days, no image intensification, so the image was viewed on a cardboard screen covered with a fluoroscopic material behind a lead-glass screen. I measured the radiation to about 30 patients, and obtained a wide variety of results, the highest dose being about 300 rad to the skin of the back, enough to produce a skin erythema[80] in some patients. My views on the doses normally given were changed when I heard of an incident at a hospital where the pathologist and the radiologist were barely on speaking terms. The pathologist opened a post-mortem demonstration to students with the remark, 'This, gentlemen, is the body of a man whose file of radiographs weighs seven and a half pounds'. Hopefully, this was not a typical patient.

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[79] See, for example, Webster (1998); White (ed.) (1998).

[80] A redness or inflammation of the skin.

The Medical Research Council (MRC) at that time had a couple of committees, one on internal radiation and one on external.[81] I got involved with them. There were two other people who were interested in this at the same time; one was Dr J Vance, who was a radiologist at Guy's, and his colleague Mr R W Stanford, the physicist. Gradually, between us, we did a number of measurements, and began to make people think that there might be something that ought to be looked at here and dealt with. This came up later when the MRC was invited to look at the question of how much radiation was received by the gonads of the population of the country, and therefore how much genetic effect there might be because of the fallout from the thermonuclear bomb tests of the early 1950s. They decided that they should also look at the amount of radiation received from every other source of ionizing radiation which might yield a significant genetic hazard to the population of the country. The first provisional estimate suggested that the greatest genetic hazard from radiation received in medicine would be from diagnostic radiology, since the use of radioisotopes then was very small, and most of the radiation administered in radiotherapy would be received by people unlikely subsequently to reproduce. This first estimate was based on very flimsy evidence of the number of radiographs taken, and on the age and sex distribution of patients subjected to the different radiological procedures. That led to the Adrian Committee, under Lord Adrian, who was then Vice-Chancellor of Cambridge.[82] He was told when he was appointed that this enquiry would take only a few months, but it took five years and considered radiation received by the gonads of patients from undergoing diagnostic radiology, radiotherapy and radioisotopes (Figure 6).

This started people thinking about the radiation doses received by patients in diagnostic radiology. Much effort went into devising equipment that would yield diagnostic results with smaller amounts of radiation, and into reviewing the techniques that radiologists used, especially in the few examinations that administered the largest amounts of radiation to patients.

Williams: That's interesting. I didn't realize that radiation protection in healthcare was invented round about that time. Were there other physicists working in the imaging rather than the protection side of radiology in that period, or was that done outside the hospital community?

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[81] For example, the MRC's Committee on Medical and Biological Applications of Nuclear Physics and its Protection Committee and its Sub-Committee, the Tolerance Doses Panel.

[82] For biographical note see page 109. Medical Research Council (1956); see also Medical Research Council. Committee on Radiological Hazards to Patients (1959, 1960, 1966); Adrian (1957); Ministry of Health (1966).

Figure 6: X-ray dosemeter and ion chamber used by the Adrian Committee Survey of Gonad Dose, developed by Sidney Osborn. See Stewart and Osborn (1959): 105; Osborn and Borrows (1958).

Osborn: That was coming along at the same time, yes.

Professor Joe McKie: In the period from 1950 to 1953, I was at St Thomas', in radiotherapy, where we were working in the diagnostic X-ray department on both imaging and protection. For imaging there was a fearsome device called the Helm camera, which was an early cineradiography device in which a large mirror focused the screen image on to a (I think it was 70 mm) film which went through like the clappers – I mean literally like the clappers; it sounded like a machine gun.[83] We were also measuring the screening time of patients and attempting to measure the dose during fluoroscopy, particularly when non-radiologists were doing the screening. The worst offenders were the chest surgeons who would walk into a room without undergoing any dark-adaptation and screen patients for quite long periods.

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[83] Professor Joe McKie wrote: 'Helm designed a concave mirror to focus an image of the full-sized fluorescent screen on to cinefilm; however, the image surface was not exactly planar, so each time the film entered the gate a steel plate with a convex surface clapped into the back of the film and pressed it into conformity with the image surface.' Letter to Dr Daphne Christie, 11 January 2006.

Barber: I would like to speak on behalf of Lloyd Kemp.[84] He came to the Royal London Hospital in 1944, having done some teaching of physics in Bradford, and his work was immensely fruitful over the coming years, with his ionization current comparator and various other devices. He impressed on me heavily that if you've got equipment that can see things other people can't see, you are really ahead of the game. He was very much a fundamental thinker. His written notes (Appendix 1) pick out one important thing: if you have not got the freedom to carry out research and development in an area, whether it's in, as it were, some of the established medical physics areas, or maybe another area, it's very difficult to follow this research through on the basis of committees outside the organization. You need to be able to follow your research through.[85]

When I came into the physics department in 1954, as a conscientious objector – in for two years, and in fact got out after 42 – there were people using 'old röntgens',[86] people using 'new röntgens', and there were people that

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[84] The Medical Physics Department was established at the Royal London Hospital in 1943 (known at this time as The London Hospital) by Dr John Read. During his three years at The London, Dr Read continued his pioneering work in the field of X-ray dosimetry. In 1946 Dr Lloyd Kemp became head of department and for the next 20 years built up the medical physics services to The London. His research interests continued the department's involvement in radiation dosimetry. His expertise resulted in the exceptional achievement of the discovery of errors in the primary UK and US measurement standards for which he received the prestigious Röntgen Prize. See Appendix 1: Lloyd Kemp's notes for the meeting. See also Kemp and Oliver (1970).

[85] Dr Barry Barber wrote: 'My recollection of Dr Kemp's arrangements at The London Hospital was that graduate staff were expected to spend about half of their time on research and development, and the rest of their time on routine work, supervision of junior staff or administration according to seniority. This element of time is where the new developments come from. I shared this freedom when our Elliott 803 computer was proposed and then installed in the early 1960s; in 1966 I became Director of The London Hospital's Operational Research Unit and Chief Management Scientist at the North East Regional Health Authority in 1975 and finally Manager of the Security and Data Protection Programme at the Information Management Centre in Birmingham (part of the NHS Executive) in 1988.' E-mail to Dr Daphne Christie, 14 July 2005.

[86] Professor Jack Fowler wrote: 'A unit of dose used before "rad" or "centigrays".' Note on draft transcript, 7 December 2005. Dr Barry Barber wrote: 'When I went to the skin department as a junior medical physicist in the mid-1950s to measure the outputs the radiographer regularly complained "bring back the pastille dose" and I never knew what he was talking about – it sounded too much like Rowntrees' fruit pastilles!' E-mail to Dr Daphne Christie, 20 June 2006. Three units of dose had been used: threshold erythema dose (TED), Pastille (B dose) and röntgen dose (R dose). The Victoreen r-meter measured doses in röntgen units; 300 R units to one pastille dose. For radium gamma rays the figure is nearer 10 000. See Glossary, page 128.

didn't know what röntgens they were using, and I was heavily impressed by that difficulty.[87]

Fowler: Yes, I think this is the first example of physics breaking away from concerns about radium and dosimetry like that, and this came in, as Sidney says, through a worry about the doses that diagnostic radiology patients were getting. At the same time, there was some thinking about how to reduce the dosage received by diagnostic radiologists. There were improvements in the X-ray films; there was some work that I was involved in in the late 1950s, about electroluminescence screens, which might be used directly to detect the radiation, the kind of things that we now see as thin screens on television and computers. But those have devolved very much into the enormous devices that are now used to detect radioisotopes, such as PET (positron emission tomography) scanners. So around this time, in the late 1950s, there was a big spread of interest in other directions in terms of physics: electronics, for example, as a subset of hospital physics.

Jennings: Can I remind you that the British X-ray Protection Committee was set up in 1921, and there was a worry about staff and radiation for a long time?[88] When I began work in the late 1940s, we had a tolerance dose as it was called, of up to 1 röntgen per week. Later this was lowered to 0.5, and then to 0.1 and

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[87] Mr Theodore Tulley wrote: 'Revision of calibration took place at about that time'. Note on draft transcript, 15 January 2006. Dr Barry Barber wrote: 'I fear that I did not do full justice to Dr Kemp's major instrumental innovations. He came to The London in 1944 as a conscientious objector and within a remarkably short time had invented the ionization current comparator, which could provide accurate dosage information for a radiation beam, even when the power source and radiation beam were fluctuating significantly. Then he went on to develop the first automatic isodose plotter, which led to his discoveries about the errors in the NPL/NBS standard realization of the röntgen. His analogue computer for calculating radiation fields from radium needles was also an interesting innovation. He showed himself to be a fundamental thinker and explored issues from first principles – always doing "the measurement too many" to check his work and always rushing back the next morning with possible solutions when we had been faced with unexplained experimental difficulties and results. The Picker Cobalt Unit with its splendid "Johns Collimator" was installed at The London Hospital in 1956 and I always thought that it was the first kilocurie cobalt unit in the UK – but perhaps I was wrong or the Mount Vernon unit installed in 1953 had a smaller source.' E-mail to Dr Daphne Christie, 14 July 2005. Mr Bob Burns wrote: 'The Johns–MacKay collimator reduced the penumbra of the gamma-ray beams from many different types of cobalt units, and is described in Johns and MacKay (1954).' Letter to Dr Daphne Christie, 21 June 2006.

[88] In 1921 the British X-ray and Radium Protection Committee presented its first radiation protection rules. Spear (1953 b).

so on.[89] We [staff] had to take at least one month's holiday a year, with plenty of sunshine. They were the conditions in those days.

Haybittle: One other aspect of radiation protection was that we were not just concerned about the dosages received by patients, but we began to be concerned about the dosages received by staff. I started at Addenbrooke's at the end of 1948, and in 1949 we began a film-badge service, run by the physics department, which gave film badges to diagnostic radiologists and all the radiographers and radiotherapists, and to people working in the university, and this film-badge service was developed and, in fact, is still going on.[90]

Dr Jean Guy: Although this refers to a much later period I don't think we should forget the contribution made by Gordon Ardran and his colleagues in Harwell in the AERE (Atomic Energy Research Establishment), regarding minimal doses of radiation to patients, in particular using air gap techniques for chest X-rays. There was staff protection using a most ingenious method of stereoscopic images of fingers and thumbs to see the effect of radiation on the people who were handling isotopes.[91]

Newing: I wanted to say a little bit about the film badges. When I first learned about the profession, as an undergraduate I had a job in UCH, under Sidney

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[89] A tolerance dose of radiation was of 0.1 röntgen per day of whole-body exposure from external sources.

[90] In 1922 film badges were first developed to measure exposure to radiation. Binks reported on this service in 1946 and stated that of the 2000 medical workers and 1000 industrial workers then examined, 70 per cent and 90 per cent respectively received less than one-tenth of the weekly tolerance dose – they would lie within the recent maximum permissible limit [Binks (1946)]. Further details are available at www.bio.cam.ac.uk/dept/Biochemistry/bioconly/manual4.pdf (visited 29 March 2006).

[91] The Atomic Energy Research Establishment (AERE) near Harwell, Oxfordshire, was established in January 1946 as the main centre for atomic energy research and development in the UK. In 1954 AERE was incorporated into the newly formed UK Atomic Energy Authority (UKAEA). Harwell and other laboratories were to assume responsibility for atomic energy research and development. It was then part of the Department of Trade and Industry. During the 1980s the slowdown of the British nuclear energy programme resulted in a greatly reduced demand for the kind of work being done by the UKAEA, which was divided in the early 1990s: UKAEA retained ownership of all land and infrastructure and of all nuclear facilities, and of businesses directly related to nuclear power. The remainder was privatized as AEA Technology and floated on the London Stock Exchange. Harwell Laboratory contained elements of both organizations, although the land and infrastructure was owned by UKAEA. The site became known as the Harwell International Business Centre. See, for example, Ardran and Crooks (1952); Ardran (1956); Ardran *et al.* (1957). See also Shepstone (1995).

Osborn, and John Clifton was there at the time. This provided an excellent introduction to medical physics. My first job after graduation was in Brighton, where I was only the second physicist to be appointed. Brian Keane was running the department at that time.[92] He was a great friend of Gottfried Spiegler and they used to meet on a weekly basis and discuss the world and what they were going to do next as far as radiation was concerned. We had a film-badge service in Brighton, and it was very much a Heath Robinson arrangement.[93] The casings of the film badges were made of cardboard and the little metal bits were stuck on to it. The physics department used to do the regular weekly processing of these films, which was done in a good old-fashioned wet darkroom. The junior physicist, which was my position at the time, spent quite a bit of time every week sorting out these films and developing them. I found that to be a most useful introduction to the physics of radiation protection.

Clifton: I think we should realize that, in this particular period, it wasn't solely radiation protection, there were other developments, one of which was crucial to the improvement of radiation dosimetry; that was Frank Farmer's work at the Middlesex in the production of the so-called Baldwin–Farmer substandard dosemeter (Figure 7).[94] This was a classic example of a physics department and a physicist developing a piece of instrumentation that was subsequently manufactured and exported worldwide.

During this time we did have iodine-131 available from the pile at Harwell, and this was nascent nuclear medicine.[95] Because iodine-131 was attracted

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[92] Dr Barry Barber wrote: 'I spent a day with Brian Keane at the Royal Sussex Hospital to find out what medical physics was about before applying for jobs at the Royal Marsden Hospital (this was my first job application and Val Mayneord did not think that I was positive enough about wanting the job), at St Bart's Hospital (Joe Rotblat and Jack Boag offered me the technician job at a time when I did not know the difference between technicians and others) and at The London Hospital [John Scarlett and Lloyd Kemp offered me the job after I had had to say "Please could they let me know now at the end of the interview because I had promised to give an answer to St Bart's the following day!"]. Everything could have turned out differently that day but Brian Keane helped fire my interest in the profession!' E-mail to Dr Daphne Christie, 20 June 2006.

[93] The name of William Heath Robinson (1872–1944) became synonymous with makeshift apparatus through his comic drawings of improbable inventions consisting largely of knotted string, clouds of steam and wooden cogwheels, often magnificently disproportionate to their purpose. See, for example, Robinson (1974).

[94] Farmer (1955).

[95] See Kraft (2006).

Figure 7: Baldwin–Farmer Dosemeter.

by the thyroid, Norman Veall,[96] who was then working with the MRC unit out at Mill Hill, produced a perspex grid which you placed round the base of the patient's neck, and then you had a heavily collimated end-window Geiger counter and you laboriously moved it from point to point upon this grid; the number of counts was recorded on a scaler and then plotted by hand to outline the iodine distribution in the thyroid.[97] This enabled the start of treatments with therapeutic quantities of iodine for thyrotoxicosis. Sir Eric Pochin with his MRC unit at UCH, London, did an enormous amount of work on the therapeutic uses of iodine during this time.[98]

McKie: There was a big variation in the appreciation of radiation hazards to staff around 1950 or before. I worked first at the Lincolnshire Radiotherapy

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[96] Dr Norman Veall (1919–91), a pioneer of nuclear medicine and medical physics, devised and made many early and original applications of radioactive materials to solve problems in medicine and physiology. See Veall (1952, 1984); Veall and Vetter (1958).

[97] Dr Jean Guy wrote: 'This method was still in use in the mid-1960s in The London Hospital when I was a medical student there'. Note on draft transcript, 26 June 2006.

[98] See Pochin (1971). For biographical note see page 119.

Centre in Scunthorpe, where Duncan Lindsay was head of department. He appreciated the hazards and was persuaded by Rolf Sievert's work on a 'tolerance dose' – Sievert was mainly concerned about genetic damage – and we worked to what we called 'Sievert tolerance' which, if I remember rightly, was about two orders of magnitude stricter than the then-existing regulations.[99] For example, all the radium handling we had to do was divided between the three physicists and several technicians, even the head of department! We each had our task to do, so that the personal doses were limited.

When I was looking for promotion, I went to a London teaching hospital (which I won't name) and was interviewed by a person whose name has been venerated here today. I described what we did – and he laughed at it, saying, 'Oh, when radium has to be used, I get my secretary to take it out of the safe over there' – pointing to a corner of his office – 'and she takes it to the theatre!'.

Dr Philip Dendy: Since John Clifton mentioned iodine-131, I wonder if I could take us back to the very beginning of this period, to 1945, and mention the contribution of Joseph [Joe] Mitchell from Cambridge.[100] With Jack Fowler sitting on one side of me and John Haybittle on the other, I do this with some trepidation because they both knew Joe for very much longer than I did. I think his work could possibly have been overlooked in this forum, because although Mitchell was a very competent physicist and his first two papers were published in theoretical physics, he was a very eminent radiotherapist.[101] He worked in the war with Sir John Cockcroft in Canada, and when by 1945 it was clear that a British Atomic Energy Authority would soon be set up with its own reactors, Mitchell was asked to chair the committee that decided which radioisotopes

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[99] Professor Joe McKie wrote: 'Sievert recommended that no radiation worker should receive more than 0.05 R/week (0.5 mSv/week). [Sievert (1947)]. This is remarkably close to the present figure of 20mSv/year.' Letter to Dr Daphne Christie, 11 January 2006.

[100] Dr Philip Dendy wrote: 'I was in Mitchell's Department from 1959 to 1975.' Note to Dr Daphne Christie, 23 June 2006. Dr Philip Dendy wrote: 'Mitchell started studying medicine at Birmingham but before returning to Birmingham to complete his clinical studies he went to St John's College, Cambridge, and took a first class in each part of the Natural Science Tripos, specializing in physics in Part II. He was Regius Professor of Physic (see note 105). Because the participants at the seminar were mostly former practising medical physicists (with a physics background) there was a tendency to overlook the contribution that persons who carried other professional labels made to the development of medical physics. I quoted Mitchell's work as an example, although others could have been mentioned, for example, Frank Ellis.' Note to Dr Daphne Christie, 23 June 2006. See page 118.

[101] See Mitchell (1932, 1933).

should be produced by the reactors for medical applications, how and in what quantities. The work was published in the *British Journal of Radiology* in December 1946, and gave an extraordinarily broad view of the state of the art at that time.[102] Mitchell listed most of the radioisotopes that would subsequently be used as tracers. Technetium-99m wasn't there but molybdenum-99 was. The radioisotopes for use in radiotherapy were listed in descending order of probable suitability as substitutes for radium, and cobalt-60 was top of the list with the now well-known advantages of cobalt-60 over other radioisotopes for external beam therapy clearly listed.[103] On the practical side Mitchell concluded, 'There is no doubt as to the practicability of manufacture of the necessary quantities of cobalt-60 by means of a pile'. He also identified the importance of cyclotron-produced isotopes, pointing out that carbon-11, nitrogen-13, and fluorine-18, were all short-lived isotopes of interest, that would be difficult, if not impossible, to produce in a pile. Finally, he gave a cogent summary of the reasons why the pile would not be a satisfactory source of high-energy neutrons for practical radiotherapy. I think this was a remarkably perceptive piece of work at that time, and I am quite sure that it acted as a very strong impetus for the capability of the UK to be at the forefront for providing a wide range of radionuclides, which I think has persisted to the present day.[104]

Fowler: Are you talking about J S Mitchell? [**Dendy:** I am indeed.] I didn't know he was a physicist. I knew him as a radiation oncologist, and he was very brilliant, and very positive about that, too. So I am delighted to hear that he was a physicist and had all these suggestions.

Sir Christopher Booth: He was a professor in Cambridge, Regius Professor of Physic.[105]

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[102] Mitchell (1946). See also Miller (1984).

[103] Sources of cobalt-60, with a half-life of 5.26 years, emitting 1.17 and 1.33 MeV gamma rays, eventually reaching several kilocuries. For an up-to-date list see www.uic.com.au/nip27.htm (visited 4 May 2006).

[104] Dr Philip Dendy wrote: '"radionuclides" is, strictly speaking, the correct terminology but "radioisotopes" was the usual terminology at the time about which we are writing.' Note on draft transcript, 26 June 2006.

[105] Mr Bob Burns wrote: 'I believe Mitchell's official title was Regius Professor of Physic at the University of Cambridge, where the word "physic" (not physics) was used with its old meaning of "the art of healing". So he was a physician, not a physicist. Although in practice and by training he was both.' Letter to Dr Daphne Christie, 1 December 2005. For biographical note see page 118. Dr John Law wrote: 'Joe Mitchell did physics before he did medicine.' Note on draft transcript, 7 January 2006.

Williams: We have established that he was a medical doctor.

Burlin: I recall that in 1953 the first cobalt-60 therapy unit was delivered to Mount Vernon Hospital, by a Canadian donor whose name I have forgotten.[106] The interesting thing was that it presaged some developments in technique, in that it was a rotational unit: the whole unit could rotate completely round the body of the patient, or could partially rotate. Also at that time Harold Johns, a

Figure 8: Measurements of lung function being made using oxygen-15 produced on the MRC cyclotron at Hammersmith Hospital, *c.* 1957–9. See note 110.

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[106] See Aldrich and Lentle (1995).

Canadian physicist, whom I am sure we all know, produced his collimator, and so various collimators were produced for shaping fields, which is done much more efficiently by computers these days.[107]

Williams: I think it's an interesting observation about the introduction of isocentrically mounted machines, whether they were cobalt units or accelerators, because that made an enormous step-change in the precision that was available in radiotherapy, because the isocentric mounting separates out the rotational degrees of freedom from the translational ones, so that it becomes very, very much easier to put the patient, or the patient's tumour, hopefully, in just the right place, at the right time. So that was a major step forward.

Professor John West: Someone mentioned the cyclotron-produced isotopes and this is perhaps a good time to refer to the Medical Research Council cyclotron at Hammersmith Hospital, which must have been one of the major advances in the applications of physics to medicine (Figure 8).[108] I am not sure when the initial planning began, but it must have been in the 1940s and the machine came on line in about 1956, or 1957, something like that. There are probably people here who know far more about this than I do. But I was fortunate to be one of the early people to use cyclotron-produced isotopes from the MRC cyclotron. Mention has been made of nitrogen-13 and carbon-11. We used oxygen-15, which was a very remarkable isotope because of its half-life of just two minutes. I remember vividly, although I am not absolutely certain of the date – I think it was 1957, and Chris Booth may remember it – that there was a meeting at the Postgraduate Medical School, chaired by John McMichael. He said, 'We are able to produce oxygen-15, with a half-life of two minutes, can anyone think of something to do with it!' This was a very remarkable opportunity, and so we thought, 'Well, we will inhale it', which we did.

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[107] See note 87. For biographical note see page 115.

[108] For his work in developing the cyclotron in the early 1930s, Ernest Lawrence of the University of California received the 1939 Nobel Prize in Physics. See, for example, Heilbron *et al.* (1981). In 1946 the Medical Research Committee recommended the construction of a medical cyclotron and in 1948 the Council determined that the cyclotron would be established as part of the Radiotherapeutic Research Unit. For a chronology of the Hammersmith Hospital MRC Cyclotron Unit see www.hammersmithimanet.com/history/history.shtml (visited 24 March 2006). Registers of cases treated at the Cyclotron Unit at Hammersmith Hospital by radium beam and linear accelerator, 1934–61; and minutes of the Radium Beam Therapy Research Committee of the Radium Institute and associated committees, 1934–45, are held by the Wellcome Library, London.

Incidentally, just previous to that, Dr Michael Ter-Pogossian, from Washington University in St Louis, where the first medical cyclotron had been produced, had come to the Unit while on a sabbatical with Gray at Mount Vernon.[109] He did a remarkable experiment. He put a bag of air, as I recall, in the deuteron beam and after a few minutes, he took a breath from this bag and put his hand over a Geiger counter, which started ticking. What had happened was that some of the nitrogen had been converted into oxygen-15, it was absorbed by the lung and transported by the blood to the hand. A rather remarkable experiment. The cyclotron had an absolutely enormous effect on my career. I should say I am not a physicist, but a physiologist and physician. We used oxygen-15 to show the regional differences of blood flow in the lung.[110] Incidentally, there were many physicists concerned with the cyclotron, although I am not sure whether they were really hospital physicists in the sense of the term that we have been using today. For example, I remember Norman Dyson, George Richard (Dick) Newbery, and, of course, Derek Vonberg, who was the Director of the Cyclotron Unit, although I think he was really an engineer as opposed to a physicist.[111] But the physicists used all sorts of sophisticated techniques, such as coincidence counting to collimate the radiation.[112] So this must have been a very dramatic moment in the application of physics to medicine in the UK.

Osborn: Mention of the early days of iodine-131 reminds me that as soon as it became available, all the research people at UCH decided they wanted to do some research with isotopes, which isotopes to use and so on. So I went down to Harwell to discuss this: what isotopes, and how we could get them and the mechanisms for doing the research. I was allowed to go into the hangar where the GLEEP[113] was built, a great big cube inside this enormous hangar. There was a ladder at one side and we were encouraged to climb up the ladder and walk around the top of it, where there were people with things on bits of string

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[109] Ter-Pogossian (1966); Ter-Pogossian and Wagner (1966); see also Ter-Pogossian and Wagner (1998).

[110] Use was made of carbon dioxide labelled with oxygen-15. When inhaled, the oxygen-15 rapidly exchanges with water in the lung, the clearance from which gives a measure of regional pulmonary blood flow. See West *et al.* (1961).

[111] Mr Derek Vonberg was Director of the MRC Cyclotron Unit from 1963 to 1986.

[112] See, for example, Hart (1968).

[113] GLEEP (Graphite Low Energy Experimental Pile) was a low energy (3 kilowatt) graphite-moderated, air-cooled nuclear reactor, the first in Western Europe, and operated until 1990.

letting them down holes into the core of the machine, the reactor, and hauling them up again. It all seemed very friendly and informal, but it did seem to do all right.

Shortly after that, a patient arrived at UCH from abroad, who had a very large thyroid cancer, so the radiotherapist said, 'Osborn, go and get some radio-iodine'. I asked how much, and the reply was, 'How much can you get urgently?' I managed to get about 80mCi, and was then told that it must be administered immediately. When I said, 'Look, the patient is in an open ward. We must take steps to prevent contamination', the reply was, 'Sorry, we can't wait for things like that'. So that afternoon the radioactive iodine was administered. Before I went home that night I went to have a look and see what was happening, and I found that the patient had had a relapse and was not very conscious, to put it that way. So I said to the ward sister that if the patient died during the night, 'then I will come in if you want me to'. 'No, you needn't bother coming in in the night'. So I said, 'Right, you must do these things: you must not touch the body, except to shut the eyes and close the mouth, and so on. Leave everything else to me, when I come in in the morning'.

She did die in the night, at about 3.00 a.m. or so, and my first job, of course, was to get four nurses gowned and gloved to lift the patient up so that the nightclothes and the bedclothes could be put into a dustbin. Then we found that the undertaker had been told about this and he said, 'Well, of course, we shall have to line the coffin with lead, I presume that a quarter of an inch will be enough'. It didn't require much to show that that would be far more dangerous to the people near the coffin than the radiation would have been. Then we discovered that she was a Jewess, but mercifully not strict. They were advised, and I don't know whether this is right, that if she had been a strict Jewess, then the only person able to deal with the body after death would be the rabbi, on his own, and rabbis get no more training in medical physics, than medical physicists do in theology. But it turned out that she was not, so it was all right, we managed. But as a result of that, the ward sister and I compiled a memorandum to the hospital authorities, pointing out that Hindus would require cremation, and quickly – the same day if possible; Muslims would only allow any surgical intervention with the body after approval by the religious authorities, and Jehovah's Witnesses would insist on having a 'watcher' by the bedside of the patient until death occurred. It is very difficult in a situation like that where there are relatives who are distressed, understandably, and you have to impose rules and regulations on what they do. I was instructed that I was to obey the official recommendations as far as I could. But I had a certain amount of discretion to modify those, if the circumstances required it. Of course, we wouldn't be able to now, we have got laws on it now, and it is much more difficult to deal with.

Williams: We may have laws on it, but it is interesting that last week I was at an IPEM Council meeting where we approved the formation of a working party to consider advice that should be given about exactly that situation, but this time when patients have had prostate implants and died of something else. In relatively recent history this problem has come to the surface again, and quite a lot of difficult discussions have taken place between pathologists, undertakers and families, in particular. If you are not doing anything next week, you will be very welcome to sit on the IPEM working party to provide this advice.

Osborn: May I add one other small thing? When the ionizing radiation regulations were being devised by the HSE (Health and Safety Executive), they had a technical working group to advise the lawyers on what it was all about, because they had no clue.[114] I was on that working group and found myself in a position of having to stand up for the health service, a very difficult job in those circumstances, because radiation protection of a patient involves very different problems from radiation protection of an employee. We had a patient in the hospital, a youngish woman, who had a heart problem and the treatment to be recommended and carried out was a very large dose of iodine-131 to knock out the thyroid. No problem. Straightforward and so on. But I worked out what the regulations, which were in draft at that point, would have to say on this when the patient got home. So at the appropriate time I said, 'You can go home tomorrow'. 'Oh', she said, 'My baby will be so glad'. Yes, she had an 18-month-old daughter. So I said to her, 'You must remember that radiation is coming from your neck all the time. It is going down gradually, but for the next week you really ought not to be cuddling the baby for more than about an hour a day, you really ought not to be in the same room as your baby for more than, should we say, six hours a day, and you must not kiss the baby.' She rang in the next day to ask, 'How soon can you take these regulations down?' I said, 'What's the problem?' She said, 'The problem is that when I was in hospital and the baby was with a baby minder, there wasn't a problem, but now baby is home and is not getting the attention she is used to receiving from mummy, all hell

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[114] Health and Safety Executive (2000).

is let loose'. So after consultation, we decided that the obvious psychological hazards for the baby were really much worse than the theoretical radiation hazards. So the regulation was not being enforced; I said, 'OK forget it'. I told this one to the lawyers and said, 'Now this is the kind of thing we have got to be careful about'. 'Well', they said, 'You can't mess about with regulations, it doesn't comply with the Directive from Europe'. I said, 'Well, it shows that your Directives from Europe are a bit offensive, not quite right'. 'Well', they said, 'We can't do anything about that'. But they did say that in a situation like that, they wouldn't take the hospital to court. Now so far that's only a verbal statement, which I have never managed to get in writing. But I make it clear here, that that verbal authority was given.

Williams: I think a lot of us have concerns about balancing of risks.

Guy: There was also a cyclotron in Birmingham – this is slightly off the theme, because this is dental radiology – I was merely a schoolgirl leaving school, and before I became a medical student I was employed as a very junior lab assistant in the physics department at Birmingham University, and we were working with fluoride-18. Teeth were immersed, after extraction, into solutions of fluoride-18 and then these were sectioned and ground down to a few microns and autoradiographed. The professor in charge was Professor John Fremlin, who was a physicist, not a medical physicist, and he was collaborating with a Dr J L Hardwick, who was the Reader in Dental Surgery. This ultimately led to the fluoridation of water in Birmingham, and presumably to the addition of fluoride in toothpaste.

Mr John Wilkinson: May I pick up on the discussion about the use of cobalt-60 to replace radium in a radium bomb? Harold Johns, in 1950 or thereabouts, picked up on this idea from J S Mitchell, and went back to Saskatoon, Canada, saying, 'I am going to do that, I am going to develop a cobalt therapy unit'. He designed a machine which was built by, I think, a company called the Eldorado Mining and Chemical Company.[115] This had a mercury shutter system. There was a reservoir of mercury that sat underneath the source and when you pressed the on button, a pump evacuated this reservoir of mercury and put it into another place, and when you pressed the off button the mercury flowed back to

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[115] For an overview of the radiopharmaceutical industry see Gelford (2004). See also http://en.wikipedia.org/wiki/Harold_E._Johns (visited 29 March 2006).

its position under the source. Unfortunately, this system tended to leak, and over a period of time some of the mercury escaped, which not only meant there was a slight radiation hazard in the room when the machine was nominally switched off, but there was also mercury vapour in the room, which was probably a bigger hazard than the radiation.

Smallwood: I didn't think I would get into this bit, because I am certainly not that old, with apologies to everyone. But the two mentions of Johns reminded me that I knew Johns – I think I got my first post because I knew him. I was appointed to my first post by Harold Miller.[116] He was clearly impressed that I had spent one of the summers when I was an undergraduate at the Ontario Cancer Institute, which was Johns' department. I am not sure what the connection was between Harold Miller and Johns, but I do know that in the IPEM (Institute of Physics and Engineering in Medicine) offices at York we have a history of Canadian medical physics, which has a great deal about Johns in it. So perhaps that would tell us what that particular connection was.[117]

Working in Johns' department was quite interesting. Most people have probably heard of Johns and Cunningham, and everybody knows it is the same type of combination as Meredith and Massey.[118] I worked for Cunningham for three months, but I saw quite a lot of Johns and Johns' house. Anybody who has lived in Ontario during the summer when the humidity is in the upper 90s, and the temperature is in the 90s, goes north to the lakes, and what Johns used to do every weekend was to take a load of his staff and students up to his cottage, along with his family, and in return for half a day's work on his property, you got a weekend enjoying yourself. I can remember one weekend where we spent one morning completing his jetty, and the afternoon waterskiing, sailing and canoeing. So I saw quite a bit there which I certainly didn't see with Harold Miller in medical physics in Sheffield.[119] The other thing was that when I was in Toronto I went out with Johns' daughter, so I spent a lot of the evenings in his house with Johns as well.

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[116] Harold Miller was President of the HPA from 1957 to 1958.

[117] See, for example, Aldrich and Lentle (eds) (1995).

[118] Johns and Cunningham (1969); Meredith and Massey (1968).

[119] Miller (1982).

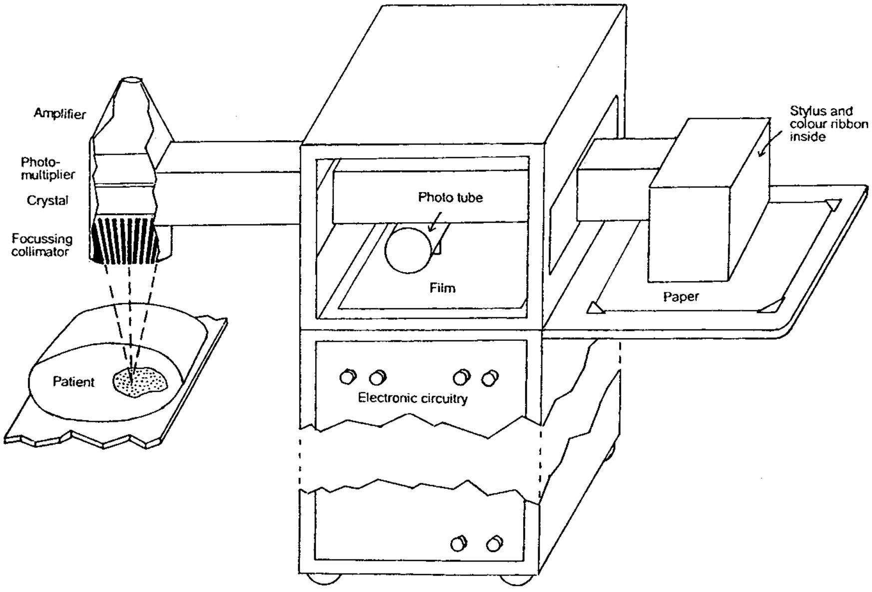

Figure 9: A simplified and cut-away drawing of a rectilinear isotope scanner, *c.*1965. The detector head containing a scintillation crystal which detects gamma rays, scans backwards and forwards over the area containing the radioactive isotope, each line being separated a few millimetres from the next. The arm supporting the detector head also supports a device that prints coloured dots on a sheet of paper and a photo tube that puts dots on a photographic film. This provides a two-dimensional view of the distribution of isotope in a patient, with the colour of dots on the paper and the density of dots on the film depending on the concentration of the isotope.

Wilkinson: Could I say that the social events in Toronto ceased as soon as his [Johns'] three daughters were suitably married![120]

Burns: About ten minutes ago John Clifton tried to change the subject to the use of radioisotopes for diagnostic purposes. Since this meeting is about the development of physics applied to medicine, perhaps someone at this meeting might be able to fill in the strange and tortuous story of the development of the relationship between medical physics and the use of radioactive isotopes for diagnostic purposes. When I went into medical physics in 1953 the use of diagnostic isotopes was essentially part of the physics department, very much a sideline, hardly noticed. There was never more than one person or usually a part-time person, devoted to the use of radioactive isotopes. This

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[120] Mr John Wilkinson wrote: 'This is not strictly true. Harold and his wife remained very hospitable, and many former colleagues will fondly remember the annual Christmas carol singing parties at their home.' Note on draft transcript, 5 January 2006.

work slowly developed, and the amount of work put into it by the medical physics department expanded, but it was still, however, medical physics. By the time I went to Westminster Hospital it was still expanding. In my final year with Westminster Hospital I was presented with a rectilinear isotope scanner (Figure 9), I don't know whether people remember it, but it was the precursor of the gamma camera. It was the last thing I wanted. It was a donation from a private source, and they tried to present it to the radiotherapy department. They didn't want it, and the diagnostic X-ray department didn't want it, so it was given to me as a physicist. I was supposed to take charge of all its work. It worked out OK to begin with, in the sense that most of the patients I received were from the radiotherapy department, and the injections of radioactive isotopes were given by the radiotherapists who also made their own diagnoses. But gradually the knowledge that I had this scanner spread throughout the hospital. Unfortunately, there was a great deal of misunderstanding about the purpose of these 'body scanners', as they were called at that time, and I once received a phone call from a surgeon who wanted a scan of the abdomen of a private patient: I asked, 'Well, but what for?' 'I just want a scan of the abdomen'. I replied, 'Yes, but what do you want to find?'. 'Just a scan to find any abnormality'. When I tried to explain why it was not possible, I was summoned up to the ward, and *ordered* to scan the patient's abdomen. So I did so, and found nothing, because no radioactive material had been administered. I wrote a negative report, and suggested that an X-ray might show up more. (This was before ultrasonic scanners became generally available.) I was under pressure to give intravenous injections of isotopes, but I refused because I wasn't medically qualified. These demands continued to increase, but by then I had decided to accept the offer of a job at the NPL.[121]

Later on, I was the Secretary of the British Committee on Radiation Units, when SI (Système International) units were being introduced, and also secretary of a subcommittee set up to discuss the use of SI units in radioactive isotope work.[122] In the meetings I became aware of the strong feelings of medical people

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[121] Mr Bob Burns wrote: 'When the use of the scanner was made my responsibility, I was not given any extra assistance, and I had to house the scanner in a small room that was used for other purposes. There are at least two lessons to be learned from this episode. First, that physicists should never be asked to take on clinical responsibilities for which they are not qualified. Second, unless it replaces something similar, when a major piece of equipment is acquired by a hospital, it may be of limited use without adequate accommodation and appropriate medical and other staff.' Letter to Dr Daphne Christie, 1 December 2005.

[122] BCRU (1973, 1982). See also www.bipm.fr/en/si/derived_units/2-2-2.html#becquerel (visited 19 September 2006).

who wanted to set up their own departments of nuclear medicine in hospitals, taking it out of the hands of physicists. For myself, I could only applaud this, because I felt that this was the right way to go. But since then, of course, it has developed even more in terms of departments of medical imaging, and I wonder whether other people here might be able to discuss this further. I have lost contact with that, but there has been a lot of development since then.

Williams: If I could make one comment and then if we could move on to ask John Mallard to expand on what Bob has been talking about, because Bob was (by his own admission) not terribly good at nuclear medicine. John Mallard is the exact opposite. But before you do, John, can Adrian say something?

Thomas: It is interesting about how the work was divided up. I started doing radiology at Hammersmith Hospital and Peter Lavender was doing the nuclear medicine there, in the nuclear medicine department. He was a nuclear medicine radiologist, not a nuclear medicine physician. We did the chest and the general nuclear medicine on the gamma camera and, in fact, the renal nuclear medicine was done by the physicist – bone scans, rectilinear scans or by probes. So it is interesting how the physicist was doing some nuclear medicine and the radiologist doing the other, and how this developed. I think it is gradually changing now, but that was how it was at that time.

Williams: Can we move on? There may be a chance to come back later, but John, would you like to say something about the expansion of physics outside radiotherapy?

Mallard: Before I move on to the isotopes, could I make a couple of points about developing radiotherapy?[123] I went to Liverpool in 1951, under Tom Chalmers, whom Alan, and John Clifton have mentioned. One of the things we had to do there – and I am sure many of you had to do the same – was radium implants which would be done in the morning or the afternoon, several of them, and then during the evening the junior physicists, which at Liverpool was me, had to work away until the early hours of the morning, reconstructing a three-dimensional model from stereographic pairs of X-rays and working out whether the implant should stay or whether one of the needles should come out or whether the whole implant should come out, because of too high a dose.

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[123] Mallard (1996 a): 64–74; see also Mallard (1995): 1855–1941.

Another point I would like to make is that in these early years of the 1950s at Liverpool there were five 250 kV X-ray generators as well as older, lower kV sets. They were all Westinghouse sets from America, and we had to apply to the Government to get US dollars – foreign currency was very scarce – to buy replacement tubes when the tubes packed up.[124] We were never refused, but it always took time, and it always meant that there was a set not working, and so on, and so forth. I would also like to mention that Len Mussell was one of the physicists there who played a major part in designing the isocentric couch for the Met-Vick[125] 8MV linear accelerator that was installed at Hammersmith in 1953.

To come back to the isotopes. I feel that the 1950s was a very exciting time; physics and engineering had played a major role in winning the war, so our stock was high. Physicists were looked upon as being whizz-kids and we had at the same time the Atomic Energy Research Establishment into which the Government was pouring money and the use of artificially produced radioisotopes was being put forward to the public as one of the peaceful uses of atomic energy.[126] The first isotope conference was held in 1951 at Oxford. It was sponsored by Harwell. The second one was in 1954, also in Oxford, and from then on the isotope conferences were organized by the International Atomic Energy Authority based in Vienna. I looked through the 1954 Proceedings of that meeting, and it's amazing what there is there: Iridium-192, yttrium-90, colloidal gold-198, bismuth-206, phosphorus-32, all for therapy. For diagnosis: iodine-131, iron-59, phosphorus-32. For animal work: sodium-24, chlorine-38, potassium-42, chromium-51, iodine-131-labelled thyroxine for example, and even some tritium products in 1954.[127] This was a tremendous boost to medical physics and research in general into biological and medical problems.

As you have already heard from many people, iodine-131 was the workhorse in the hospitals, for the thyroid work, and phosphorus-32 for polycythaemia treatment. We had to measure uptakes and John has mentioned the method

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[124] For a history of Westinghouse see www.westinghouse.com/timeline.html (visited 20 July 2006).

[125] Professor John Mallard wrote: 'Short for Metropolitan-Vickers, the manufacturers.' Note on draft transcript, 5 January 2006.

[126] See note 91.

[127] Johnston *et al.* (eds) (1954)*:* 416, 68s. See also Kraft (2006).

which I thought came from Joe Rotblat at Bart's, of trying to form images of the thyroid with a collimated Geiger counter, and taking counts at points over the neck, recording them on graph paper, and drawing isocount lines.[128] We were also having to measure the uptake in the thyroid with a straightforward Geiger counter, having to measure the excretion in the urine by putting samples of urine in a well around a Geiger counter, similarly for blood samples.[129] Geiger counters then came with lead-coated cathodes, which gave us a gain of five in sensitivity for iodine-131 counting over the straightforward copper cathode. They had a long dead time of 100–200 microseconds. For every count we had to do a dead-time correction, which we were doing on our slide rules.[130] Norman Veall brought in an array of Geiger counters to go round a Winchester bottle,[131] so that the urine measurement became much more pleasant. You collected it in the Winchester, plonked it in the hole and measured the activity. The early hot labs in those days for isotopes were pretty crude, straightforward lead blocks to start with for shielding and the interlocking lead blocks didn't come in until the mid-1950s.[132] Hand and finger doses were high, I have got a numb finger here which I am pretty sure is due to dispensing iodine-131 therapy doses which were, to use the old units, 100 to 150 millicuries. You can work that out for yourselves![133] Remote handling did not really get started until the 1960s.

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[128] Overseeing all of the physics work at Bart's was Joseph Rotblat, winner of the Nobel Peace Prize, 1995, who was Professor of Physics at the Medical College of St Bartholomew's Hospital, from 1949 to 1976. Professor John Mallard wrote: 'Isocount lines were contours oE equal counts per unit time. They shared regions high in radioactivity, and gave a very crude "image" of the thyroid shape and abnormal "hot" or "cold" spots'. Note on draft transcript, 26 June 2006.

[129] Professor John Mallard wrote: 'A range of sizes and shapes of Geiger counter became available from Twentieth Century Electronics Ltd.' Note on draft transcript, 5 January 2006.

[130] Professor John Mallard wrote: 'Each time a Geiger–Müller counter detected (counted) a radiation event within it, it could not detect another until it had recovered – the dead-time – during which further events are missed. Thus the time counts are somewhat greater than the measured counts – the dead-time correction.' Note on draft transcript, 26 June 2006.

[131] A large bottle with a short narrow neck, used for carrying or storing liquid chemicals.

[132] Professor John Mallard wrote: ' "Hot-lab" was the nickname for the laboratory where radioactive materials were chemically prepared, measured and dispensed for administration to patients'. Note on draft transcript, 26 June 2006.

[133] Professor John Mallard wrote: 'About 4000 to 5000 megabecquerels (MBq)'. Note on draft transcript, 26 June 2006.

Electronic counting was done in the early 1950s by homemade circuitry, built by ourselves, and it wasn't until about 1953, 1954 or so, that a magnificent range of scalers, ratemeters, power units, designed and built at Harwell, became available for us to use. Then we had the spin-off companies: E K Cole at Southend, Isotopes Development Limited at Aldermaston.[134] They were all using thermionic valves, 10 microseconds dead-time, very large units.

The field didn't really become 'nucleonic' until the 1960s, using the smaller thermionic bulbs. Always with a lot of faults, we had to be good at repairing them ourselves, and I remember struggling for almost a year to get £200 for a spare scaler unit to keep our counting work going in the hospital isotope lab and clinic. My boss at Hammersmith at that time, in 1953, was Dr Leslie Hermann Clark, a wonderful gentleman, a real gentleman, and he was a co-author of a very good radiation textbook of the time.[135] Then we got dekatrons, you remember the red light going round, each rotation being ten counts, that made the counting a lot easier. Eventually we got the transistor miniaturization and all that sort of thing. Early scintillation counters appeared, again in the 1950s, a very exciting time. Russell Herbert, one of my bosses at Liverpool, used a small calcium tungstate crystal on an early photomultiplier tube. Then we had thallium-activated sodium iodide around about 1955 onwards, so that thyroid uptakes were then done with a half-inch diameter crystal. You could then buy scintillation counters from E K Cole Ltd or from Burndept Ltd. These were a tremendous gain in sensitivity, the thyroid counting became much more simple, easier, and the imaging became a lot more accurate and easier. You could put multihole-focused collimators in front of the sodium iodide counter and get a better spatial resolution. Then Ben Cassen in Los Angeles built the first automatic thyroid scanner, I think that was 1952.[136] It had a mechanical movement of the counter, it was angled to avoid the chin, as it went over the thyroid, and had a typewriter printout, the typed marks got closer together the higher count rate, so that you had a very crude, newspaper-like type of image. In 1957 at Hammersmith we built the very first whole-body scanner, with a

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[134] See, for example, www.thevalvepage.com/tvmanu/ekco/ekco.htm (site visited 30 March 2006); Kraft (2006).

[135] Russ *et al.* (1928).

[136] In 1950, Dr Benedict Cassen assembled the first automated scanning system, which consisted of a motor-driven scintillation detector coupled to a relay printer. The scanner was used to image thyroid glands after the administration of radioiodine. Initial studies led to the extensive use of the scanning system for thyroid imaging during the early 1950s. See Cassen and Curtis (1951); Cassen *et al.* (1951); Blahd (1996).

Figure 10: The first whole-body isotope scanner (homemade) in use for detecting a brain tumour, *c.* 1959. Mr Peachey is operating the electronics which has dekatrons display, at the Hammersmith Hospital, London. See notes 137, 138 and 139.

Figure 11: The first digital whole-body SPECT scanner (homemade). Dr Ian Keyes is operating the machine at the Royal Infirmary, Aberdeen, *c.* 1968.

similar printout, but we changed the colour as well with the counting-rate – all built for a few hundred pounds (sterling).[137]

We used it not only for thyroids (with iodine-131), but for livers (with gold-198 colloid) for finding tumours, and for kidneys (with iodine-131 diodrast).[138] We also used it to detect and localize brain tumours using arsenic-74 and arsenic-72 from the Hammersmith cyclotron, which has been mentioned.[139] Jack Fowler was part of that isotope programme. They are positron emitters, so we had two counters, one above the head and one below the head and moved them over the brain, connected in coincidence so that you only picked up the annihilation gamma rays. It was a very successful series, 85 per cent accurate to everybody's surprise, and it was the beginning of PET (positron-emission tomography).[140] A whole period of brain-tumour imaging followed using a single collimated counter and iodine-131-labelled human serum albumin, which Harwell very quickly produced after that. It was the test of choice until X-ray CT came along from the mid-1970s onwards. So all these various scans and tests which came in in the early 1950s and later, got us in collaboration with a wide range of medics, in all different specialties: neurosurgeons, physicians, general surgeons, endocrinologists and so on. So we got to be known a lot more outside radiotherapy and, I hope, appreciated and respected.

One thing I would like to bring out is that in this period of the 1950s there was a tremendous sense of pioneering. We had a brand new NHS, and here we were trying to make it one of the best in the world. Also it was the new Elizabethan era, a new Queen, and full of hope that everything was going to be wonderful. The administrators of that time were interested in what we did! At the Hammersmith, the Chairman of the Board of Governors, Sir Desmond Morton, who was in fact one of Churchill's secretaries in the war, came to see

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[137] In Mallard's scanner, the colour of the marks also changed and quantified the counting rates over the image: the boundaries of the colour changes indicated the isocount lines, and the shape, size and defects of the thyroid gland could be perceived.

[138] Mallard and Peachey (1959); see also International Federation of Medical and Biological Engineering (IFMBG) (1960): 511–2. Professor John Mallard wrote: 'Diodrast was an X-ray contrast material which passed through the kidneys. When labelled with iodine-131 it enabled an image of the kidney which showed regions of malfunction such as tumours.' Note on draft transcript, 26 June 2006.

[139] Brownell and Sweet (1953); Mallard *et al.* (1961). See also IFMBG (1960).

[140] For an overview see Mallard (2003).

our scanner at work; the Hospital Secretary came to see it – they were fascinated with it, so it helped us to get money to build the next one and so on. Even up in Aberdeen in the 1960s, when I went up there in 1965, the Medical Superintendent took a personal interest in what we were trying to do and he was very good in getting me space for the early scanners and all that sort of thing, which eventually became the Nuclear Medicine Department.[141] Maybe I am out of touch, but we seem to have lost that rapport nowadays.

The next big step forward in the isotope work was technetium-99m. Introduced by Paul Harper of Chicago in 1954, with a low radiation dose, short half-life [six hours], very low energy, 140 keV, which enabled much finer resolution and more efficient collimators to be designed, providing images with much more detail. Very quickly, Harwell and the Radiochemical Centre, Amersham,[142] which was just starting, produced the whole range of labelled chemicals that they previously had with iodine-131, all labelled with technetium, and that gave a terrific boost to clinical nuclear medicine throughout the country. Nowadays I think that combined with gamma cameras, combined with SPECT and PET, taking Aberdeen as being a fairly typical nuclear medicine service, serving about two-thirds of a million people, 11 000 or 12 000 patients a year go through with about 20 tests, 12 of them using imaging.

Gamma cameras have been mentioned. Hal Anger built the first one in 1958, and the first European gamma camera was built by E K Cole in the early 1960s, with a 5-inch diameter sodium iodide detector, viewed by only seven photomultipliers – compare that with the huge number of photomultipliers today! The non-uniformities were dreadful, and so on and so forth, but it was the beginning – it made a brain image possible in half the time of the scanners. Nuclear Enterprises Ltd in Edinburgh took over, built and sold gamma cameras until the mid-1970s, but as always, IGE (International General Electric), Picker, Toshiba, Technicare, Siemens, Philips, gradually forced it out of business. Nigel Trott and I wrote up some of the early history of nuclear medicine in the UK and dealt also with quite a few of these developments in a chapter in *Twentieth Century Physics*, which was produced by the Institute of Physics.[143] Some of the collaborators in that chapter are here today.

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[141] Mallard (1996 b).

[142] Grove (1957); Kraft (2006).

[143] Mallard and Trott (1979); Mallard (1995): 1855–1941. See also Cohen and Trott (1995).

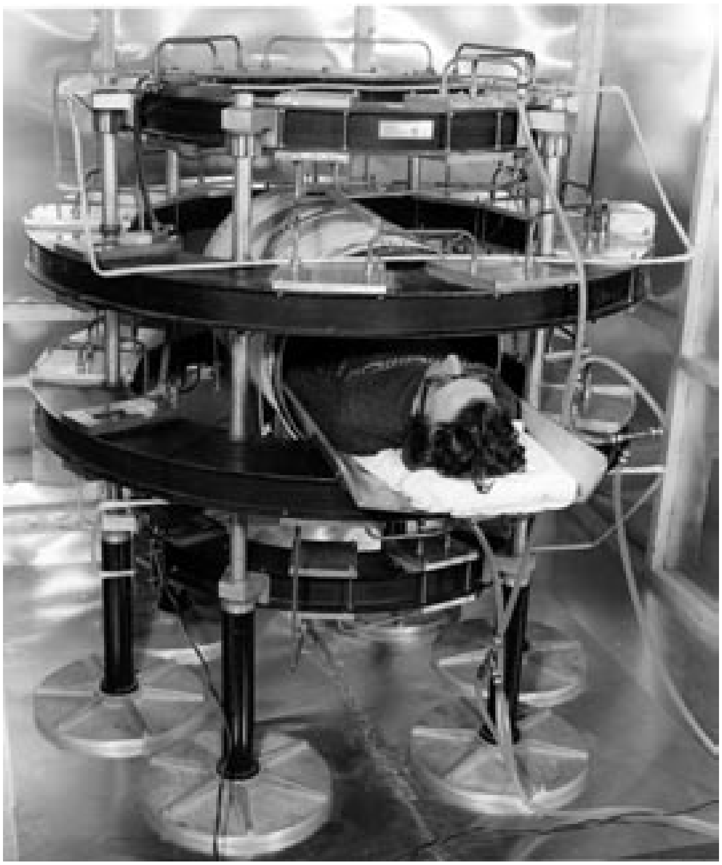

Figure 12: The first whole-body MRI of clinical usefulness (homemade) in the medical physics department, Aberdeen, *c.* 1980; Dr Hutchison is in the position of a patient.

If I may, sir, I would like to criticize UK industry. I think they lost out badly. The early whole-body scanner was made for a while by Isotope Development Ltd at Aldermaston, but the Picker Magna Scanner took over the market. The early UK gamma cameras were ousted by Picker, Toshiba, Philips, Siemens, IGE and it was just the same with the nuclear medicine tomography scanner: it was done for a while by J and P of Reading, but they lost out to Cleon, which became part of Technicare. EMI even lost X-ray CT, with which they had led the world for several years.

With MRI we did try, with a small company in Aberdeen, but we were quickly beaten by the same old gang: IGE, Technicare, Siemens, Philips, Picker and so on. I wonder if there's something wrong. It's not only the getting of the money, we only got £1.5 million for our little company to set up with MRI, and that same year IGE spent $112 million on pure R&D alone to improve their machines' performance. So we were beaten before we started.[144] Also, a thought occurred to me the other day. The NHS, for all its wonders, is only one customer and you have to go through your hospitals to persuade them that you want this machine; the hospital has to go to the Health Board to persuade them that you want this machine; the Board has to go to the Region and so on and so forth up the administrative chain. By the time you have done all that, the company trying to make it in Britain has gone bust and you have to buy an American or a German one.[145]

Finally, we should give a very good vote of thanks to all those physicists and scientists who were at Harwell, they did a marvellous job, they produced a wonderful range of isotopes for us. They did it very much in the early days on a personal basis, even delivering them by car, and I rather wonder if perhaps we didn't say 'thank you' enough at the time; when they were late delivering and we had got an operating theatre and had a neurosurgeon and a physician breathing down our necks for their isotopes. I am pointing at you, Chris [Sir Christopher Booth], as one of them! When they did eventually come, we weren't too pleased with them, and we really should say retrospectively, a very good thank you to all the scientists at Harwell. Thank you very much.[146]

Williams: I think it is right to recognize that medical physics isn't just provided by hospital physicists. The whole range of people working as academics, working in industry, working in public sector bodies contributed just as much in different ways.

Ashton: Just a quick word, not about isotopes, but about radiotherapy and cobalt units, and to remind people that one of the first people in England to make cobalt units was a railway engine company, the Hunslet Engine Company

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[144] See Blume (1992)*:* 190–224; Christie and Tansey (1998): 1–72.

[145] Professor John Mallard wrote: 'It is interesting that Asahi in Japan sold 145 MRI imagers virtually identical to ours, and flourished.' Note on draft transcript, 5 January 2006. Dr Jean Guy wrote: 'This is an old problem. See Andrews (1921).' Note on draft transcript, 26 June 2006.

[146] This has been outlined in Mallard (1994). Available online at www.iomp.org/iomphistory.htm (visited 14 March 2006).

in Leeds, who changed from doing steam engines to making cobalt units.[147] But, of course, all the people in the south didn't buy anything from them,[148] so don't just blame the Americans.

Clifton: Seeing as we have got some controversy, can I come back on that one to Tom, because certainly Hunslet Precision Engineering Ltd made the first telecobalt units for Cookridge Hospital, Leeds, which was a cobalt bomb mounted on a Cincinatti-style pillar drill.[149]

Ashton: It came from Halifax[150] and it was a converted radial drill and it didn't come from Cincinatti.[151] (See Figure 13.)

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[147] Mr Bob Burns wrote: 'Not quite true. They continued making steam engines until 1971, and diesel engines until 1995, when they closed down. I do not know when they stopped making cobalt units.' Letter from Mr Bob Burns to Mr Tom Ashton, 12 January 2006. Tom Ashton replied: 'I meant to imply that they changed their range of products to include radiotherapy cobalt units. In fact later, they went on to make small three-wheeled cars, but then in the early 1960s, the Fairey Aviation Company took over the design of radiocobalt units from Hunslet Precision Engineering Ltd and they installed the third cobalt unit in Cookridge Hospital.' E-mail to Dr Daphne Christie from Mr Tom Ashton, 13 January 2006. See Ward and Ashton (1997): 22–5.

[148] Mr Bob Burns wrote: 'Definitely not true. At least if by "south" you mean England. *The IAEA Directory of High-Energy Radiotherapy Centres,* 1970 edn, lists Hunslet cobalt units installed at Bournemouth, Cambridge, Coventry, Hull (2), Leeds (2), Hammersmith, Royal Marsden, UCH (2), Northampton, Southampton, Stoke-on-Trent and Wolverhampton. And in the Irish Republic at Cork and Dublin (2). I could not find any installed overseas. Very wisely, the company marketed their cobalt units under the name of Hunslet Precision Engineering Ltd. I remember visiting Mount Vernon in 1953 to see the first cobalt unit to be installed in the UK. Alan McKenzie told me a few months ago that there was now only one clinical cobalt unit still operating in the UK – all the rest have been replaced by linear accelerators. Truly the end of an era.' Letter to Mr Tom Ashton from Mr Bob Burns, 12 January 2006. See Ward and Ashton (1997).

[149] See Ellis (1978).

[150] Mr Tom Ashton wrote: 'The drill was from William Asquith Ltd of Halifax and was modified to take the weight of the heavy lead-filled cylinder rather than the upward thrust of the drill action.' Note on draft transcript, 9 January 2006. See Ward and Ashton (1997)*:* 23. Mr Tom Ashton wrote: ' "It came from Halifax" is correct as I was referring to the mounting of the treatment head which was a modified radial drill mounting as described above.' E-mail to Dr Daphne Christie 25 June 2006.

[151] Mr Theodore Tulley wrote: 'Our first cobalt machine in Hull was also from Hunslet – a "special" allowing experimental close-up use for the University, as well as whole-body treatments.' Note on draft transcript, 15 January 2006.

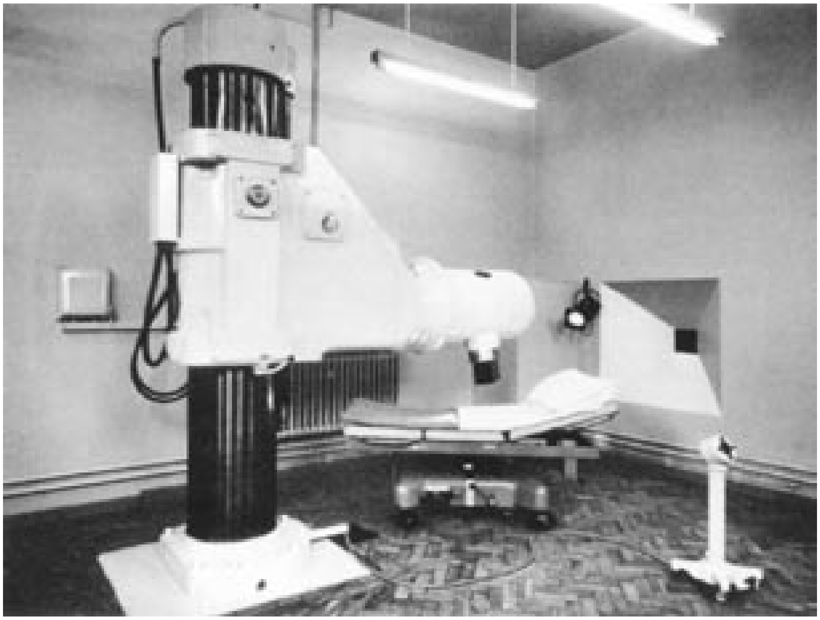

Figure 13: The Dual Purpose Radiocobalt Unit in the patient 'treatment' position (1956). Also the viewing window (on the right wall) and the movement control pedestal. See Ward and Ashton (1997): 24.

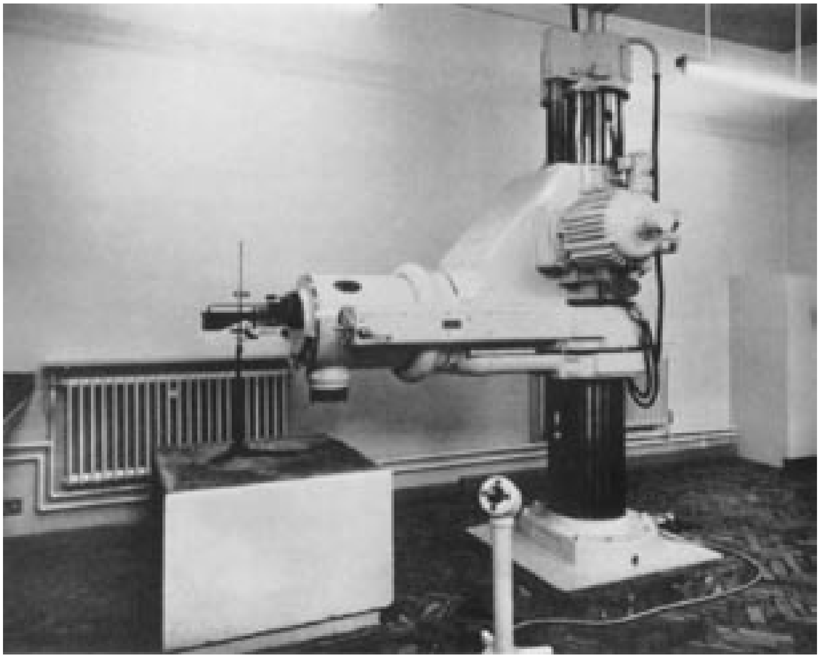

Figure 14: The unit in the radiochemistry 'research' position, before the 'research' protective shield was made. See Ward and Ashton (1997): 25.

Clifton: But we subsequently had one of their first rotating cobalt machines. It was my task to travel up and down from UCH to Leeds to discuss with Hunslet [Engine Company] the development of this machine, and one of the things I asked was, 'Well, what do we do about a maintenance contract?' The response was, 'Eh lad, we build it like a locomotive, you don't need a maintenance contract, bring it back in 25 years and we will rebuild it'. It was still going until about ten years ago when UCH radiotherapy was relocated to the Middlesex Hospital. [**From the floor:** And that was a waste of a maintenance contract.]

Barber: Just to follow on from Bob Burns' comment about SI units and the excitement thereof. On the day of the Moorgate crash,[152] the Royal London Hospital got closed down for its non-emergency activity, and a senior surgeon, who obviously found himself at a bit of a loose end, summoned me to go to the physicians' and surgeons' sitting room and he then spent half an hour with me on two propositions. One of them was that SI units were going to be the death of British surgery as we know it, and the second was equally peculiar, that if I wrote to the Department of Health they would change their policy.

Williams: What I would like to do is to pick up some loose ends from what we have been talking about before, and then move on to nonradiation physics. Talking about loose ends, it was Peter Tothill who wanted to add a comment to what John Mallard has just said about nuclear medicine.

Dr Peter Tothill: John Mallard has given a very good introduction to the early use of radioisotopes, leading up to the imaging field, in which, of course, he has been a great pioneer. But I would like to mention that in the really early days the radioisotope work was done in medical physics departments because they had the equipment, they had the Geiger counters and so on. That led to the physicists involved, at least some of them, becoming more than just physicists. People like Norman Veall, whom I would single out, learnt physiology, knew about electrolytes, about blood flow, about thyroid uptake, renal function and who used the early equipment – especially scintillation counters when they came in – in many fields of medicine. The Veall and Vetter book of 1958, *Radioisotopes in Clinical Research and Diagnosis,* was my bible.[153] So that even before there was imaging, medical physics or physicists were quite intimately

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[152] On 28 February 1975 a London underground train crashed at Moorgate, London, killing the driver and 43 passengers and injuring more than 70.

[153] Veall and Vetter (1958).

involved with the use of radioisotopes. John also made reference to a debt to Harwell, and I would echo that, but add also the Radiochemical Centre, before it became Amersham International.[154] They were very friendly, and it worked both ways. We used to test radiopharmaceuticals for them, on ourselves mainly, at least to start with. That is something that would be totally forbidden these days, but it was mutually beneficial. Other agencies involved in the development of the use of radioisotopes included, for example, the International Atomic Energy Agency (IEAE), who, by running conferences, instituting workshops, sponsoring the use of radionuclides in various places around the world, allowed some of us who acted as scientific missionaries, to take it abroad. So there are these other agencies. The other group that led up to ARSAC (Administration of Radioactive Substances Advisory Committee) was the MRC Radioisotope Advisory Panel, which pretended it had powers that it didn't have. When legislation was brought in, ARSAC was developed, and that led to useful, certainly safer, use of radionuclides.[155]

Booth: Just to carry on from John Mallard's presentation about the development of isotopes in the 1950s. That period at Hammersmith was a disorganized period by comparison with today. The clinical departments in medicine were using isotopes, we ran our own show, we had our own equipment, we did our own dosimetry, and did all those things entirely independent of a department of nuclear physics at the time. It wasn't satisfactory, I don't think, in any sense, and whether patients got more radioactivity as a result of having different dosages from different centres within the department of medicine, I have no idea. I worked mainly on B12. I would like to pay tribute particularly to commercial organizations, especially Glaxo. The radioactive vitamin B12, which I worked on, was produced by J M Bradley at Hammersmith in the cyclotron unit from a friend of his at the Birmingham cyclotron who produced some very highly active cobalt-56, with very high specificity. That was given to Lester Smith, who isolated vitamin B12 at Glaxo and he is the man who made the material that we then used. So it was more than the commercial organizations that were involved in making isotopes; there were other people in industry and other areas who were making isotopes at the same time. The question I would like to ask is, has anybody any idea whether any of that relatively indiscriminate use of

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[154] For a history of Amersham International see ww4.amershambiosciences.com/aptrix/upp01077.nsf/Content/about_us_company_history (visited 19 June 2006). See also Kraft (2006).

[155] See www.advisorybodies.doh.gov.uk/arsac/ (visited 30 March 2006).

isotope-labelled material ever led to an illness in anybody who was submitted to those tests?

Williams: I think that's a rhetorical question, probably most people don't know.

Guy: Nobody really knows what happened to the people who received the first X-rays and if they actually had a physical burn, so it is not likely that we would know about the isotopes either.[156]

Haggith: The Adrian Committee survey of radiation doses in diagnostic radiology took physicists out to hospitals of all sorts, and got to see the problems there, like the chest physician who thought that collimators were a nuisance, and so did without them.[157] This made visualization of the chest more likely and the patients got whole-body radiation, of course. The other important thing was that outlying hospitals were introduced to physicists.

Radioisotopes, I think, had a similar profound influence. The apparatus and expertise in measuring and handling radioactivity was in physics. And radioisotopes having an application in absolutely every branch of medicine, meant that consultants who were interested in their application came to the medical physics department and got to know us well, and found there what other expertise there was. We had a workshop and statistics and electronics expertise, and computer knowledge, and it really did have a great effect on the spread of medical physics.

Williams: John [Haggith], you mentioned the fact that there was an opportunity for physicists to get out into every hospital. One of the areas where that was done mainly was in supporting diagnostic radiology and I know John Law wants to say a few words about diagnostic radiology.

Dr John Law: John Clifton asked me to talk for two or three minutes and to be provocative. I will try to do both. In the early 1960s I don't think there was any well-defined role for physicists in diagnostic X-ray work. Their involvement

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[156] In 1918 Dr Eugene W Caldwell died of X-ray burns in New York. He was Director of X-ray in New York City's Bellevue Hospital and received the fatal burns in the course of his X-ray research. See Pusey and Caldwell (1903).

[157] Ministry of Health (1966).

was patchy, usually temporary and *ad hoc*, and mostly by those whose main responsibility was in radiotherapy. There were three main ways in which we tended to get involved. The first was in protection and we have already heard a certain amount about that. In the years after the first edition of the *Code of Practice* (1957), probably the main need was simply to check that there was any filtration at all in the X-ray beam, or that there was any beam limitation. If you found a light beam diaphragm on an X-ray tube in those days, that was a luxury.

The Adrian Committee work has already been referred to. That was largely done by staff drawn from radiotherapy and while, no doubt useful, liaisons and collaborations were struck up, it wasn't always plain sailing. One senior and very even-tempered physicist (John Greening), halfway through a series of Adrian Committee measurements was so exasperated by the radiologist that he turned to the basic grade physicist who was working with him and said, 'Pack it all up, we are going back to the department'. I heard that from the basic grade years afterwards.

The second way in which we used to get involved was teaching. In those days there was no FRCR (Fellowship of the Royal College of Radiologists) Part I, instead there was the Diploma in Medical Radiology (DMR), and for most people that was run by something called the London Conjoint Board.[158] Their syllabus was in a time warp, drawing heavily from the school A-level syllabus. This did little to encourage radiologists to recognize the usefulness of physics. There were a few university-based departments, including Aberdeen, Edinburgh and Liverpool, who had recognition from the Royal College of Radiologists. These departments had freedom over drawing up their syllabuses and we used this to the full to foster good relations with radiologist colleagues. I think it was in about 1970 that the Faculty[159] pulled the plug on the London DMR and set up their own Part I.

The third way, and it did happen occasionally, was in making improvements to image quality and equipment performance and the checking thereof. One example was Greening's method of checking diagnostic X-ray tube kV, which

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[158] The London Conjoint Board administered Diplomas in Medical Radiology of the Universities of Cambridge and London, and for a time, Liverpool and Bristol. Later, hospital physicists were recruited to assist with the Diploma examination of the Society (later College) of Radiographers.

[159] Dr Jean Guy wrote: 'The Fellowship of the Royal College of Radiologists was preceded by the Fellowship of the Faculty of Radiologists (FFR). The Faculty of Radiologists ran from 1939 to 1975; the Royal College of Radiologists from 1975.' Note on draft transcript 26 June 2006.

he devised after watching an engineer struggle to use the sphere gap method. It is a very elegant piece of medical physics that has tended to be overlooked, probably because he published it in a physics journal, and not in a medical physics journal[160] – *Physics in Medicine and Biology* – came just too late to catch that particular brilliant piece of work.[161] The Leeds department was already, by the late 1950s, doing a lot of work on CCTV (closed circuit television chains) and image intensification. They knew that the day-to-day user of equipment is the last person to notice any deterioration; therefore you must have objective tests at three- or six-monthly intervals to detect decline in performance. Unfortunately, when it came to publishing their work, they adopted rather a perfectionist approach, and this was a bit discouraging to those of us who weren't quite sure how and where to begin, and had limited resources for doing so. It was too easy to wait until Leeds had sorted out some of the problems that they laid such emphasis on. Much later, John Cameron of Wisconsin said to me, 'If a thing is worth doing at all, it is worth doing badly'.[162] In other words, do a little, however inadequate, it's going to be better than nothing; in hindsight we could have benefited from having that attitude in this country rather earlier.

In the late 1960s, the HPA set up topic groups, I think invented by Jack Fowler. This was one of the most beneficial developments we have had, because they started producing reports and organizing meetings, and the Diagnostic Radiology Topic Group was particularly active (**Fowler**: Yes, I did, with John Newall). Their work was slow to be taken up at first, partly because the membership tended to be drawn from those departments that had plentiful resources, and this was reflected in the reports that they wrote. They didn't always make sufficient allowance for the problems of departments who didn't have such resources. The Liverpool Department, in the days when Trevor Henshaw was working virtually single-handed, also did a lot to foster the monitoring of image intensifier performance. There has already been mention of Ardran's work, but we haven't yet mentioned the penetrameter he devised with Harry E Crooks, who was his radiographer at Harwell.[163] That was one of the biggest advances

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[160] See Greening (1955).

[161] *Physics in Medicine and Biology* was first published in 1956. See the fiftieth anniversary issue [*Physics in Medicine and Biology* **51:** 7 July 2006] where several of the authors also attended this Witness Seminar.

[162] For a biographical note see pages 111–2.

[163] See United Kingdom Atomic Energy Authority Research Group Memorandum (1967): G M Ardran and H E Crooks, Diagnostic X-Ray Beam Quality. Wellcome Library Archives, GC/250/5. See also Ardran and Crooks (1968).

for physics in checking diagnostic X-ray tube performance; it came in 1968, and was followed in about 1974 by the NPL setting up a calibration service for penetrameters. Those penetrameters underlie the basis of all the automatic instantaneous kV meters that our successors enjoy using today.

We have been asked to give a flavour of what it was like at the time. To come back to the topic groups: two or three years after they were set up I got a letter inviting me to join the Diagnostic Radiology Topic Group. I was astonished, because I knew who was on it – they were all high-powered, brilliant chaps, so how was I going to manage to contribute anything? I rang up Roy Parker who had sent me the letter and I started off saying, 'Why me? I don't have the experience, I can't contribute in that group'. 'John,' he said, cutting me short, 'If you can keep that lot's feet on the ground, you'll be doing us all a great service.' I hope that's sufficient provocation for you, Chairman.

Williams: Quite provocative. A couple of comments I would make about that. You mention education and the fact that the syllabus for the radiologists and the radiotherapists was a little bit bizarre and more like A-level physics and not much use to them. But there was another use in that education and that is that all of us who were involved in educating radiologists and radiotherapists got to know those radiotherapists who later became the consultants, and therefore they knew that we knew what they didn't know, and that was probably a very important way in which physicists in the radiation's sphere managed to get influence for the benefit of the patients and the health service.

The other thing I particularly liked was the John Cameron reference, if it needs doing, you could do it badly. Tomorrow morning I am talking at an IPEM meeting about the most recent development in radiotherapy physics, IMRT (Intensity Modulated Radiotherapy), and I am hoping to make exactly the same point. The UK was right at the front of the development of the science and the technology for IMRT. It's now right at the back of the queue in terms of number of patients who are benefiting from it, because everyone in the UK is trying too hard for perfection, and if we just got on and did it, there would be enormous benefit to all our patients. So that's a cue, but it jumps a bit too far forward. Jack Fowler wants to say a few words about the development of megavoltage radiotherapy and the contribution of physics to that. If we could have five or ten minutes on that and then we will move on to the nonionizing things.

Fowler: Before I do, John, [Mallard] you have just reminded me that when we were at Hammersmith, we were beginning to get into the business of looking at the resolution limits of scanners, John Mallard's scanner, how many events did you have in a square centimetre? All of that led into the quite sophisticated ways of defining the definition of the diagnostic machines as well. Now happily we talk about thousands of events (scintillations) detected per cubic millimetre to make an image these days. Going back to Hammersmith in the early 1950s, that's where a lot of things happened. John Mallard mentioned that a linear accelerator, the 8 MV [megavolt] Metrovic model,[164] was put into the MRC building in 1953. It is important to note this date, because it is way ahead and before anything clinical that Varian did, and Varian are now probably the world leaders in making linear accelerators, with all of their computerized things that we do with accelerators these days. But that was a development of Metrovic based on a British invention, which probably helped us to win the Second World War, and this was the magnetrons that gave us radar which was very good for detecting aircraft. But later on Varian came in with ignitrons, which are much better oscillators and do better with linear accelerators. When the Americans invented these ignitrons, aircraft carrying radar could pick up the submarines that had their snorkel devices, and that led to the success of the allies in the 'Battle of the Atlantic' in 1943.[165] So all of this is part of the history of the development of linear accelerators and it's tragic to see that what was going on with Metrovic and Philips in those early days has now been taken over entirely by the Americans and the Swedes and the Germans. I think the biggest advantage in radiotherapy has been the introduction of linear accelerators and computers into treatment planning. That has really meant that we can begin to put the dose just where we want it and, with certain reservations, also smaller doses in normal tissues than in tumours.

Williams: The development of the technology of radiotherapy seems to me to be very interesting and oscillatory as well, because we started off before the megavoltage era where the limitations of radiotherapy were that the energy wasn't high enough and therefore we couldn't get the dose into the middle of the patient, so linear accelerators and cobalt units got invented and then we could do that, but we didn't really know what was inside the patients, and then fortunately CT scanning came along. Then we realized that we knew a little bit too much about what was inside the patient and we couldn't treat it

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[164] The Metropolitan Vickers referred to by Professor Mallard is on page 50. See Thwaites and Tuohy (2006).

[165] Churchill nicknamed the encounter the 'Battle of the Atlantic'.

well enough. So we had to invent multi-leaf collimators, conformal therapy to do it practically. Then we found that multi-leaf collimators didn't give quite close enough conformal therapy, so intensity-modulated radiotherapy came along. Now I think the limitation is imaging again in radiotherapy, so we are going round in circles, and treatment planning is now starting to be informed by molecular imaging, positron emission tomography (PET) and MR, so in another ten years we will probably find that the limitation is again in the treatment delivery end. So if anyone has got any ideas about what to do next in radiotherapy equipment, now is the time to get the patent on it.

Wilkinson: It is interesting to note that the cobalt machine and the first linear accelerator both started treating patients within the space of about two years. But there was a period afterwards, of about three decades, when people were arguing as to whether you should buy a cobalt machine or a linear accelerator as your workhorse machine, and there were credible arguments on both sides. The big argument in favour of the cobalt unit was the one that John Clifton referred to earlier, and that was, once it was installed, it needed very little maintenance, whereas your accelerator probably required someone to service it, maybe monthly, in order to keep it working. It's interesting to note that it was about 30 years before the main manufacturers stopped making cobalt units, and I suspect that the reason people ceased buying them was because of the cost ultimately of disposing of the cobalt sources.

Can I say something about the introduction of computers into radiotherapy? There was a big time gap between the first publication on the use of computers in radiotherapy, which was by K C Tsien in 1955, and the use of computers becoming widespread in hospitals.[166] There was a panel meeting in Vienna, an IAEA [International Atomic Energy Agency] meeting, where they were discussing treatment planning in radiotherapy and this was in 1965. They said, 'What about computers? Do they have a real role in treatment planning?' A conference was held at Downing College, Cambridge, in 1966 which John Clifton attended,[167] and the idea was to invite everyone worldwide who had used computers in radiotherapy, and one or two people that had just shown an interest, and they got about 40 people to the meeting. When they decided that they would have another meeting some two years later, the numbers had

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[166] Tsien (1955).

[167] See Mitchell and Sterling (1967).

doubled, and in fact I got the impression that the people interested in computing in radiotherapy had an exponential growth with a doubling time of about two years, because at the first meeting that I went to in this series, there were about 300 people. The first small computer, the first dedicated in-house computer, came into use in about 1968 and this was a machine produced by B D Spear and Company in the USA. These 'programmed consoles' initially went into six chosen hospitals in the USA and Canada. The one that went in at Toronto was evaluated by a young MSc student, Jo Milan, and he subsequently went to the Royal Marsden Hospital, London to work with Roy Bentley, where they developed the Rad8 System (based on a PDP8) which probably became the leading small in-house computer for radiotherapy in the 1970s and well into the 1980s.[168]

Barber: Can I follow that in the sense that John Clifton at UCH and myself at the Royal London Hospital in about 1964 had access to Elliott 803 computers?[169] Elliott Medical Automation Ltd had some treatment-planning software and from that time picking up on the developments worldwide and in-house, I wound up with a commission from the DHSS and the BIR to write a report on

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[168] Mr Theodore Tulley wrote: 'We acquired a PDP11 in the late 1980s – I don't think we implemented Rad8 on it. We had previously done some work on the University of Hull's ICL 1905, to which we had an on-line connection.' E-mail to Dr Daphne Christie, 14 July 2006. Mr John Wilkinson wrote: 'Rad8s were originally marketed by Digital Equipment Corporation (DEC), and then from about 1976 by EMI. Towards the end of that decade the system was updated to allow dose distributions to be superimposed on CT scans and rebranded as "Emiplan" running on a Data General Eclipse computer. EMI sold their radiotherapy business to General Electric *c.* 1980/1 and at this stage Emiplan was renamed RT/Plan. Subsequently RT/Plan became "Target" and there was another change of hardware, this time to a Sun Microsystems computer. Throughout all these changes of name and hardware the basic dose calculation algorithm remained the same, i.e. that which Bentley and Milan had developed for the Rad8 in 1970, and there was continuity in the development and support teams, particularly in Laurence Coleman who has worked on this project for about 30 years. In fact I think that it is still possible to buy a direct descendent of the Rad8 – now known as prism-tps – from Laurence at Prism Microsystems (www.prism.co.uk).' E-mail to Dr Daphne Christie, 27 June 2006.

[169] The London Hospital installed an Elliott 803 digital computer on 1 November 1964. See Barber and Abbott (1966). See also Barber and Abbott (1972): 31–46. Dr Barry Barber wrote: 'An outline of the key findings of the BIR/DHSS report was published as Barber (1975): 801–5; 1097–1102.' E-mail to Dr Daphne Christie, 20 June 2006. Dr Barry Barber provided a number of internal reports from the Medical Physics Department at The London Hospital and these will be deposited with the records of this meeting in Archives and Manuscripts, Wellcome Library, London.

radiation treatment planning systems in 1973/4, looking at, as it were, which way we ought to jump in an evaluation sense.[170] It was interesting, a bit like buying cars: you know they are coming, and they are going to be great, but yet if you want to buy a car you have got to buy one that is available. At that particular time, if you wanted to get away from a batch processing regional system (as used for the excellent work they were doing at Glasgow under J M A Lenihan with Stuart Orr and Charlie Hope and so forth, with their SCRAP system) you needed to go to the Rad8, developed by Roy Bentley and Jo Milan at the Royal Marsden Hospital, which was available and did two-dimensional planning and it was marvellous and immediate. However, other systems were being developed from the partnership with John Haybittle and Gordon Jameson, the Middlesex–Addenbrooke's work, which again was going to be brilliant and do three-dimensional planning and lots of other exciting things, but on the other hand, at that stage you couldn't quite yet buy it! Incidentally, it is amazing how different the computerized treatment-planning process is now from that on which I trained at the Royal London Hospital; computers have totally revolutionized it.

The only other point to make is that there was a period in the 1960s and 1970s when the only basic resource in the hospital and health service for doing any computing at all, unless you could persuade some university research student to do it in the vacation or as a special project, was the medical physics department.

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[170] Dr Barry Barber wrote: 'My own activities utilized that research and development time to explore operational research and computing activities (very much with the support of Dr Lloyd Kemp), helping to make the case for the installation of the Elliott 803 computer from the scientific and medical points of view. The hospital was quite explicit in arranging for the machine to be available for about half of its time for nonfinancial work. During this period I had a serious interest in medical physics applications of computers but when I was appointed to be Director of the newly created Operational Research Unit, these matters became the responsibility of the new Head of Department, Monty Cohen. The only exception to this was when I was contracted by the BIR and the DHSS to carry out an evaluation of the UK radiation treatment-planning systems in 1973. My report, Computerized Dose Computation Report for DHSS/BIR, December 1973, provided a snapshot of computerized treatment-planning activity by December 1973.' Edited e-mail to Daphne Christie, 14 July 2005. Elliott Medical Automation Ltd had radiation treatment-planning software in the 1960s and work was also undertaken on large regional computers. The next step was the development of the Rad8 system. A copy of this report was kindly provided by Dr Barry Barber and will be deposited with the records of this meeting in Archives and Manuscripts, Wellcome Library, London.

A lot of them jumped in and developed all sorts of systems for the NHS well outside the specific requirements of medical physical departments and I think that's something that perhaps ought to be recognized.[171]

Clifton: Can I follow up briefly on what Barry has said? The Medical Automation Unit came into UCH, according to my records, in 1962.[172] The very point you make is that, having introduced this Medical Automation Unit with the blessing of the Board, they then looked round and said, 'Well, who can use it?' The only people that they could think of that could use it, that were sufficiently numerate, were the physics department and the biochemistry department. So we ended up, on the one hand doing radiation treatment-planning, and on the other, like my colleague Professor Flynn, doing quality control in biochemistry.[173] One went on from that to do other things – John Wilkinson has also referred to the various conferences. The first of those in Vienna was called by the IAEA,[174] as John said, to see whether there was any use for computers in radiotherapy. The interesting thing that follows from that is that the following meeting, which was held in Cambridge,[175] at which I happened to act as secretary, the chair of that was the same Professor Joe Mitchell, so here was Joe again, moving in yet another direction. The early meetings of this International Conference on Computers in Radiotherapy, as it became known, spent a lot of time arguing about the accuracy of the dosimetry; which algorithm was most accurate.[176] That was on

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[171] Dr Barry Barber wrote: 'During the 1960s and 1970s there was an acute shortage of facilities for the development of information systems within the NHS. In some cases individuals had access to large university systems or to Regional Computer Centres, various small or mini machines installed in hospitals. However, even when there was access to computing facilities, there was a major limitation in the availability of people who could utilize these facilities. For quite some time the scientific staff of medical physics departments – and to a lesser extent of clinical laboratories – were the only people who could fill this gap. This was a major feature of the development of some systems at some hospitals and the "computing specialty" became an important medical physics activity, as had happened earlier with nuclear medicine, radiation protection and ultrasonics. In other cases there were ludicrous situations where computing science students were given serious projects to undertake on behalf of hospitals which were quite beyond their capabilities. In the reverse situation, the hospitals would not have dreamt of giving medical students projects to undertake in advanced surgery or the design of major medical facilities!' Edited E-mail to Dr Daphne Christie, 14 July 2005.

[172] Payne (1966).

[173] See, for example, Flynn *et al.* (1976).

[174] IAEA (1966). See also page 67.

[175] See Mitchell and Sterling (1967).

[176] See, for example, Glicksman *et al.* (1971).

the one hand. On the other hand, we were arguing with the radiotherapists saying, 'Well, it is OK, we are within 2 per cent, 3 per cent, or whatever, how accurately can you tell us the volume of the tumour?' And they hadn't got a clue. It was, here we have a series of X-ray shadows, how do we guess what is the tumour? You have now seen that imaging has pushed accuracy in the other direction. We can now, particularly with MR scanning and so on, get a very accurate definition. So now we are back to saying, 'How accurately can we do the dosimetry?' So as Peter has said, what goes around comes around.

Williams: I wouldn't totally agree with what you have just said, in that an individual can claim a degree of accuracy about localizing a tumour, but there are quite a lot of studies showing that no two individuals agree with each other and the biggest study was done at Leuven in Belgium, where they had about 20 practitioners outlining brain tumours, and what they found was that if they treated the volume of tissue which everybody agreed about, they would treat something the size of a pea, and if they treated all the tissues that anybody thought was involved, they would end up treating the whole brain. So the radiotherapist or clinical oncologist,[177] is still to some extent the weak link in the chain.

Burlin: I was going to confirm what other speakers have said. My perception is that from about 1965, the advances have been largely driven by the increasing power of the computer. I listened to Sidney Osborn saying his machine was a slide rule; that is what I started with at Mount Vernon, and as I left I was allowed to turn something with a handle. I got to Hammersmith Hospital in 1957 and thought I was in heaven because the maternity unit allowed me to use a calculator which had three storage registers and moved electrically. You could do the calculations I was interested in (how a measuring instrument 'a cavity' perturbed the radiation field) much more quickly. By the time I had finished, all my PhD students were doing Monte Carlo calculations and could do anything.[178] Similarly with the world of radiation protection. When I was

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[177] Professor Peter Williams wrote: 'The latter being the current title of those who practise radiotherapy in the UK.' E-mail to Dr Daphne Christie, 13 July 2006.

[178] The Monte Carlo calculation is a statistical method, involving random sampling techniques and often computer simulation, of approximating the solution of complex physical or mathematical systems.

interested in quantities of radiation protection, by that time, in 1979, people were calculating the absorption all over the body, for all sorts of fields, neutrons, photons, electrons, and you could pick quantities which covered things on the safe side. It was all down to the power of the computer.

Williams: The power of the computer gives you the speed. Sometimes I wonder whether it gives you too much accuracy and you lose sight of what's important. The slide rule has got exactly the right precision for calculations in our business, you can get a slide rule to operate at around about 1 per cent which is good enough, and as David Green used to say to me when pocket calculators came into use in the 1970s, 'You can't scratch your back with a pocket calculator!'[179]

Osborn: I am reminded, sir, that during the war, when we were working with radiotherapy, we couldn't think of radiation in terms of three-dimensional pictures, there was no mechanism for it. We couldn't think in terms of two-dimensional pictures, single-plane isodose curves hadn't come in.[180] All we had were the central axis depth–dose curves for ranges of field size and radiation energy compiled by Mayneord and Lamerton – a vastly different procedure from present-day practice.

Williams: It does make you wonder why it worked, doesn't it, and perhaps what the observation is, that radiotherapy is quite a robust therapy, and what we have been doing for the last 30 years isn't making it much better, just refining it. But in the 1940s and 1950s radiotherapy worked. Can I suggest that we move away now from ionizing radiations and its applications, to talk about the expansion of the applications of physics to non-radiation areas, and I know that Dr Blau, who is sitting quietly at the back, would like to say a quick word about something.

Dr Joseph Blau: Can I invite all you physicists to come to the ward and see what physics we use every day: the stethoscope, with which we listen to the heart, lungs, abdomen and even clicking jaw joints. I have always been puzzled by how the noise gets up these rubber tubes so quickly and efficiently. We use

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[179] For a history of the introduction of calculators, see, for example, www.xnumber.com/xnumber/frame_timeline.htm (visited 19 June 2006).

[180] Mr Bob Burns wrote: 'In a body exposed to ionizing radiation, isodose curves are lines of equal absorbed dose in a plane or volume, expressed as a percentage of the dose at a given reference point such as the maximum dose.' Letter to Dr Daphne Christie, 16 September 2006.

an ophthalmoscope, which I believe was invented by Thomas Young,[181] and it is the only place that we can see a nerve in life. We can also see small arteries, and veins, and if the capillaries have leaked, we see the exudates. As clinical neurologists we use nerve conduction and measure where the current is being stopped at the wrist or pressure on the nerve at the elbow. We can see the nerves under the microscope, and what you physicists call 'insulating material' we have in the nerves as myelin – I don't know how God learnt about that. As a neurologist, we use the brain waves (EEG) that travel from the brain, through the fluid enclosing the brain, through two layers of bone, through the bone marrow between the two bones, through the muscles and the skin, and then we pick up the brain waves of the person who has fits or even during normal sleep. I would like to ask a question of you all, could we possibly get these waves outside the brain, because that would explain how we transfer thoughts to other people if we do?

Williams: We are all silent on the off-chance that the brainwaves will pass and tell you the answer to that. I think the reason we are silent is we assume automatically, this telepathy will work. I don't know the answer; it will be interesting to see if other people do.

The interesting observation, though, is that I have been involved quite a lot recently in talking to the Institute of Physics and the Engineering Council, about the problem of young people not being interested or retaining an interest in science and the problems of falling applications to physics courses in universities at a time when media studies is going up by a factor of four. One of the issues that keeps coming up is that society in general, young people in general, just don't appreciate that there is physics and engineering in nearly everything we

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[181] Dr Joseph Blau wrote: 'Hermann von Helmholtz invented the ophthalmoscope in 1850 with which we can see the only nerve in life, as well as small arteries, and veins; also if capillaries have leaked we see exudates indicating increased pressure inside the skull or diseases at the back of the eye. The ophthalmoscope was introduced into clinical medicine by Thomas Young, a pioneer British ophthalmologist who wrote a treatise *On the Mechanics of the Eye*. These two eminent men were close friends; from their work arose the Young–Helmholtz theory of colour vision. Helmholtz established another physics–medicine relationship by measuring the rate of nerve transmission of impulses by means of electric currents, that later became electromyography enabling nerve conduction to be measured when conduction is slowed in nerves at the wrist or elbow due to pressure, and in various parts of the body if nerves are inflamed or degenerating from diverse causes. We can see the nerves under the microscope.' E-mail to Dr Daphne Christie, 14 June 2006. See http://dodd.cmcvellore.ac.in/hom/29%20-%20Helmhotz.html (visited 7 September 2006). See also Keeler (2002); http://archopht.ama-assn.org/cgi/reprint/120/2/194.pdf#search=%22helm%20concave%20mirror%22 (visited 19 September 2006).

do, and so these day-to-day devices that you are talking about being used in practice, most people will not recognize those as being things based on physics and engineering, and that's a bit worrying. So there is a promotional issue we have got to deal with, to make sure it's not just the really high-tech, exciting, exotic applications that get noted, but also the more mundane, but very useful and ubiquitous ones.

Thomas: Seeing brainwaves outside the body is an application of mysticism to medicine rather than physics, I suppose. I was very privileged at UCH when I was a medical student to be taught by Jonathan Miller and he was working on a chap called John Elliotson, interested in mesmerism, animal magnetism and the early aspects of early nineteenth-century magnetic physics. There were two ladies in Tottenham Court Road whom he could put into a mesmeric trance, and he would then take them round the wards of UCH and they would see inside the bodies of patients and tell John Elliotson what was wrong. He was appointed as Professor of Medicine at UCH in 1824, obviously he had to leave. It's the whole excitement of what is going on. I went to medical school in 1972, so I started medicine as CT scanning came in, there was a huge excitement there. I was taken by the late Bill Goodie, who died last year, to see the new EMI scanner at UCH, it was immensely exciting to see these, at that time, very primitive EM scans of the brain. Nuclear medicine was starting, ultrasound was starting with Dr Shirley at UCH, and I started at Hammersmith when MRI was starting. It is immensely exciting, I think, whenever young people come to the department – I have been having students from the local schools come to my department, and one of the local physics teachers brings students doing A level now to the department. We have stethoscopes – the stethoscope is nineteenth-century technology. You can do ultrasound now, you can see the heart, you can see the heart moving, and you can see the excitement on young people's faces when you show them MRI scans, you show them ultrasound scans. You show a patient their heart beating, you say this is your heart, these are the valves of your heart, and you can see the excitement there. It is about getting this excitement through to people. When people see these images in real life, it is exciting.

West: Let me just add something about the teaching of physics to students in high school and, in the USA, in college. I have been responsible for directing the course of physiology for medical students for some 30 years, and we have noticed a definite change in the ability of students to understand physical principles, even quite simple ones, like pressures and flows and resistance, and elasticity and so on. It's very dramatic and we wondered the reason for this. I think it is because worldwide the teaching of physics has not been given the emphasis that it had in the past. This change is something relatively new, certainly in the last ten or 15 years, we have definitely noticed a difference. However, if you ask the young medical students about DNA or something like that, of course, they know all about it. So molecular biology seems to have taken over from simple physical principles, and it makes the teaching of physiology, particularly in the cardiovascular and respiratory systems, much more difficult, because people have very strange ideas about these simple principles.

Newing: Can I say something about the teaching of physics? There are fewer and fewer people wanting to do physics at university, we are told, and the reason often is that it's perceived as a very difficult subject, which is one of the reasons why they go off and do media studies, as you mentioned. Down the road at the Institute of Physics there's a small group of four or five of us who are currently in the process of preparing a presentation about medical physics for GCSE and A-level students – the idea being that the exciting bit of physics is often medical physics, and so if we can get students switched on to medical physics, then we might get rather more students at universities doing physics. I am delighted to say we have got quite a lot of support for this project, so much so that we are hoping to produce a PowerPoint presentation for teachers on the medical physics option. There is one about ionizing radiation, and one about nonionizing radiation, and this will hopefully, after a roll-out to a few schools, go to all secondary schools in the country.[182] We hope that might do some good.

Professor Roland Blackwell: If I can just pick up on several things. One is related to funding and the links with industry, another is to projects that didn't work, and the third is related to the development of devices.

If I may start off saying that in 1966 I was appointed to help with an evaluation that the Department of Health was undertaking of five machines of the original commercially available ultrasound scanner. The scanners were made by Smiths Industries, and later became the Diasonograph ultrasound scanner.[183]

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[182] Professor Angela Newing wrote: 'This is now completed.' Note on draft transcript, 26 June 2006. See, for example, Cook *et al.* (2006); www.teachingmedicalphysics.org.uk (visited 5 July 2006). See also Gibson *et al.* (2006), at http://ej.iop.org/links/q75/dySUarOoK1Eh6SmANnAIXA/pe6401.pdf (visited 5 July 2006).

[183] Professor John Clifton wrote: 'Kelvin, Bottomley and Baird Ltd became Kelvin and Hughes Ltd, and was subsequently merged into Smiths Industries.' Note to Dr Daphne Christie, 29 September 2006.

Figure 15: The world's first 'static' ultrasonic scanner using articulated arms. Professor Peter Wells wrote: 'This scanner, the precursor of the commercially manufactured machines which were in universal routine clinical use until the mid-1980s, when real-time scanners were introduced, was designed and constructed by Peter Wells at Bristol General Hospital in 1962–3. The electronics system was supplied by Nuclear Enterprises of Glasgow. The work was supported by a grant from the Medical Research Council.' Letter to Dr Daphne Christie, 5 January 2006.

Figure 16: Diasonograph Diagnostic Ultrasound Unit.[184]

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[184] See Christie and Tansey (1998); Tansey and Christie (2000). Freely available online following the links to Publications from www.ucl.ac.uk/histmed.

(See Figure 15.) Our radiologists looked at the images, and said, 'These images are totally hopeless, go away'.

I was extremely fortunate that at UCH there was an obstetrician named Ernie Kohorn, later Professor Kohorn,[185] who came to me and said, 'Actually, I think we can make something of this'. So I kept the machine going with some success. Later Stuart Campbell came along and developed his fetal growth charts on this machine and we were able to help him identify the variations and errors.[186] Those charts are still widely used. So that was one form of support for medical physics. I came into the medical physics department to undertake an evaluation but then 'fell off the back' of the original evaluation and stayed on in the department to do other things.

Later on we undertook a study on ultrasonic tissue characterization, funded by industrial money from GEC Medical Ltd. The problem was that our ideas required computing power beyond that then available. So our technique didn't work very well. Later, because computing power had caught up, we wanted an extension of the funding. I remember going along to GEC in Wembley. At dinnertime we were taken into the executive dining room. As I walked to our table I unfortunately caught my foot under the chair of the Head of Research, who was eating there, and whipped his chair away from under him so that he was left dangling from his table. For some reason, they wouldn't extend our grant!

Really what I wanted to say was that in the 'good old days' you didn't have to go through the process of defining your project exactly. You knew that there was a clinical need because you were involved in the clinic, and did what you could to develop equipment to meet those needs. Sometimes it worked, and sometimes it didn't, but you could get on and be innovative without having to go through endless rounds of proposals, modifying those proposals, setting all your benchmarks throughout the time of the project, and then accounting exactly for the work you had done. You were able to make mistakes, and to correct them on the spot and to be iterative. This freedom actually achieved results.

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[185] Professor Ernie Kohorn published with Professor Stuart Campbell on placental localization. See, for example, Campbell and Kohorn (1968); Tansey and Christie (2000)*:* 30, 45. Freely available online following the links to Publications from www.ucl.ac.uk/histmed.

[186] See Tansey and Christie (2000)*:* 29–30, 39–40, 43–44, 45, 53–56. Freely available online following the links to Publications from www.ucl.ac.uk/histmed.

Williams: That concept of academic freedom has changed perhaps a little bit since those days. You had the freedom to make mistakes, and to take chances and now everything is totally accountable, so you don't take risks, and you don't take chances.

McKie: Could I add to what Angela said about children? The Glasgow department, as part of its contribution to Einstein Year, is taking around the community an exhibition about medical imaging to try to stimulate interest in physics, and, of course, the Institute of Physics is doing quite a lot of other things as well.[187]

Could I go on to say something about a field that he's not mentioned, and that is acoustics – not 'hyperacoustics' but just ordinary acoustics? When John Lenihan started his Glasgow department, he was a great believer in seeing things that needed to be done and doing them. One of these things was to repair hearing aids and so he set up (this would be around 1954) a little workshop to do this. From that, he saw that the audiometers throughout the country were not calibrated at all: there was no systematic calibration and so they varied enormously in their accuracy. He set up a scheme in the department for calibrating audiometers throughout Scotland, which was later taken over (including the staff) by the Scottish branch of the Royal National Institute for the Deaf and a couple of years later was extended throughout the rest of the UK. Those of us who are hard-of-hearing owe a debt to that vision.

That was the type of thing that he did. And in the fields of radionuclides and ultrasonics, he set up training courses for clinicians. His 'isotope courses' started about 1955 – perhaps it was 1956 – and ran for about ten years. If you look at the student list, it looks like a 'Who's going to be who', because practically every major head of department in Scotland (and quite a lot of other places too) had gone through his course. This went on until systematic teaching got into the syllabus of the various specialities.

He did the same thing for ultrasonics, running courses for many years until it became widely known. That was a great contribution to developing these specialties.

Williams: I think your comment about audiology is interesting, because it demonstrates that medical physics hasn't been a closed profession, it has been a

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[187] See, for example, the medical physics CD-ROM for schools, developed by Dr Adam Gibson, UCL Medical Physics and Bioengineering, www.ucl.ac.uk/news/news-articles/06061302 (visited 19 June 2006).

bit metastatic every now and then. The group of people who started off doing audiological science within physics departments are separated out, and almost created their own subdiscipline of audiological science. They have now got a separate training scheme and have provided excellent service across the country. Can we move on a little bit to Peter Wells?

Wells: I don't know if you realize that today is 5 July, and it was on 5 July 1948 that the NHS was established, so this is the 57th anniversary of the establishment of the NHS.[188] It's some 12 years younger than I am, but I think a good deal more worn out. [**From the floor:** I think we ought to be the judge of that.] So we are talking about the postwar period, and in order to prepare this little presentation I looked at John Haggith's chapter in *The History of the HPA, 1943–1983* and found some interesting statistics. If you take 100 physicists working in medicine, in medical applications, in 1967, 31 were working in radiotherapy, 30 in radionuclides, five in diagnostic radiology, ten in radiation protection, and 24 in all the other subjects. By 1982, with the same 100 physicists, and of course there were a lot more physicists by 1982, the percentage had fallen to 20 in radiotherapy from 31, 22 from 30 in radionuclides, six had gone up from five in diagnostic radiology, radiation protection gone down to eight, and the remainder, ultrasound, physiological monitoring, clinical engineering, medical electronics, and other areas, increased from 24 to 44.[189] So there was a great deal of increase in activities beyond that of ionizing radiation. Also, and this is very interesting too, the large number of extra physicists, or even engineers, working in 1982 in relation to 1967, many of them were ladies, and if we were to have this meeting in 50 years' time, we would find that the men were outnumbered by the ladies very likely, and I don't think that's a bad thing, quite a civilizing influence to have those ladies coming in.

People have referred to the effect of the war, people wanting not to be involved in the war; they have referred to the postwar legacy, and I think the postwar legacy has been very important for medical physics. We have heard about magnetrons, for example. The science and technology that resulted from the Second World War, the tremendous efforts that went into that, have had tremendous impact in peacetime. So the 'swords into ploughshares' aspect of that has been very important. Not only that, the war gave the opportunity to some of our greatest role models to flourish. Hounsfield, for example, before

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[188] Rivett (1998).

[189] Haggith (ed.) (1983).

the war was working in a draftsman's office in a builder's firm. He went into the war as an RAF volunteer and was a radar mechanic, and then went on to invent the CT scanner and to win the Nobel Prize.[190] Similarly, Peter Mansfield, who won the Nobel Prize in relation to MRI, had been a printer's compositor, and the war changed what he was able to do.[191] There have also been huge changes in the NHS and nobody has referred to Sir Solly Zuckerman's report on hospital scientific and technical services which was published in 1968.[192] Zuckerman recommended the establishment of several independent departments of science within the health service. Four branches of pathology in biological sciences in one department, nuclear medicine in another department, medical physics in another, biomedical engineering and applied physiology in another. As a matter of fact, that was a bit of a nuisance for the department in which I worked, where nuclear medicine was within medical physics. This encouraged the creation of a new breed of doctors, the nuclear medicine specialists, maybe before their time, and although there are some examples of people who were spectacularly successful clinicians, spectacularly successful, the developments in nuclear medicine did take place and continued to take place in medical physics to quite a large extent, despite what Zuckerman recommended.

We have heard about the scant encouragement that we received from our brother and sister physicists and that's certainly something of which I am aware. It is only this year that my photograph was stuck up in the department of physics in Bristol as somebody of whom they are not completely ashamed. So I am quite pleased that has happened at last.

Training schemes have been mentioned. That was very important for this expansion out of ionizing radiations into other areas too, and although the relationship between the university and the hospital at the medical physics level may have been one of disdain, there was in reality a very good relationship between the great teaching hospitals and the medical schools. There was a knock-for-knock relationship; there wasn't a question of cost. The hospital administrators, the hospital secretary were very proud of what medical physicists

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[190] See http://nobelprize.org/nobel_prizes/medicine/laureates/1979/hounsfield-autobio.html (visited 7 September 2006). For biographical note see pages 114–5. See also Hounsfield (1973); Ambrose (1973); Christie and Tansey (1998).

[191] Professor Sir Peter Mansfield FRS (b. 1933) has been Professor Emeritus of Physics, University of Nottingham since 1994. See http://nobelprize.org/nobel_prizes/medicine/laureates/2003/ (visited 7 September 2006). For biographical note see pages 116–7. See also Christie and Tansey (1998): 1–72.

[192] Sir Solly Zuckerman (1904–93), for biographical note see page 123.

were doing, and the universities also assisted a good deal in that way. So suffice it to say that, as a result of all these changes driven by the postwar enthusiasm and the creation of the NHS, the new disciplines of physiological measurement, biomaterials and prosthetics, lasers, infrared, microscopy, computing and information management, emerged.

May I have a couple of ticks for personal reminiscence? I was fortunate at school to have been perceived to be, quite correctly, hopeless at maths. So I was put into the biology stream, and the physics that I learned, and more or less the only physics that I still claim to understand, was that in Gilbert Stead's book.[193] I am an engineer and it is interesting to see that this meeting is about medical physics – but I don't distinguish very much between medical physics and medical engineering. All I know is that I don't know enough physics and I wish I knew a bit more. So it was Gilbert Stead who taught me what physics I know. Physics in the medical curriculum has already been referred to. My own particular area in ultrasound, again I read in the *History of the HPA* that Lloyd Hopwood, a pioneer of medical ultrasound, a long, long time ago, looked at the biological effects of ultrasound.[194] Physiotherapy in the 1930s, surgery in the 1950s, and I worked a little on surgical applications in the 1960s, and then imaging, and we had a similar experience to Roland Blackwell in Bristol. One of these machines was offered to the radiologists, and the professor of radiology said he didn't want anything to do with it, he didn't want his staff wasting their time working on that. I don't believe that radiologists would take that view now, I think that generation of radiologists has disappeared, and that we wouldn't depend on the physicists to rescue it. In Bristol, however, it was Dr Herbert Freundlich (head of the department of medical physics) who rescued ultrasound from the disdain of the radiologists and who facilitated the work with the physicians, particularly with gastroenterologists.[195]

Just to end on a provocative note, I think that what we have heard about today have sometimes been incremental advances in clinical applications of physics, and their responding to clinical needs certainly, and that's what we call 'clinical pull'. But if you look at the step-changes that have taken place – the invention of

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[193] Stead and Allsopp (1964).

[194] Hopwood (1931); Haggith (ed.) (1983)*:* 102. For biographical note see page 114.

[195] For biographical note see page 113.

CT, the invention of MRI, even some inventions in ultrasound – they are what you might call 'disruptive technologies', they change the practice of medicine, and they are often not initiated by the busy working doctors, because they are so busy they can't stand back and see what science can offer. I think that the advances that have taken place have sometimes been despite the doctors' scepticism. I wonder whether the explosion in medical physics that has occurred has been because physicists and engineers have begun to understand physics applied to medicine, as opposed to simply engineering and physics and trying to apply it to medicine. They have begun to understand the medical problems, they have learned, they obviously don't treat the patients, but they become multidisciplinary specialists instead of being pure physicists, and I think that's actually jolly nice.

Williams: I agree with that. John, you wanted to say something.

Haybittle: I wanted to pick up briefly on the last point that Roland Blackwell raised about being accountable. When I was at Cambridge, Addenbrooke's was a teaching hospital and therefore I was being paid out of the budget for the teaching hospital. Any hospital in the East Anglian region might ask me to go out and look at its X-ray equipment, or do something of this sort, or give some advice. The University often asked me to do something. I never had to account for this – nobody sent any bills to anybody. Yet it was a system that worked extremely well.

Smallwood: Although my first degree is in physics and I have got an MSc in solid-state physics, like Peter I think of myself as an engineer, because most of what I have done in medical physics departments was electronics. Perhaps I can mention two areas of electronics, which I think had a significant effect on patient management. The first was a very simple one and was the first thing I did when I was appointed as a medical physicist in 1970. In 1970 if you had a spinal injury and survived the results of the accident, you were most likely to die from kidney failure. The first job that I was dropped into was with a urologist to look at the natural history of bladder function in paraplegics following their injury. For two years, I put together a set of transducers and amplifiers, we had to build the amplifiers, to measure the pressures in the bladder and in the rectum, to measure the flow and also to measure the electrical signal from the pelvic floor as a measure of muscular contraction.[196] This was a very interesting example of

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[196] Thomas *et al.* (1975).

funding. We have talked about funding being generally available and this was the first grant that I ever applied for: I got quotes for everything that we needed and I added up the costs and they came to about £10 000, hugely expensive by today's standards, for what was an incredibly simple piece of equipment. We put the grant in and it took months and months and months for it to come through. When we got the grant I went back to all the manufacturers and got new quotes and, of course, all the quotes had gone up. So I thought, 'Oh, I will not be able to afford this', and then I looked at the amount of money we had been given and what the sum of all the quotes was and we had been given more money than the quotes, and I thought there is something very strange going on here. So I went back to what I had done originally and I found that I had added it up wrong. My original figures were £1000 too much and nobody had noticed – that's 10 per cent too much and nobody had noticed. So we actually got everything. We spent two years measuring what was going on with the natural history of bladder function and we also did things then, which you certainly couldn't do now.

One of the problems was that the bladder in a paraplegic, shortly after their injury, acts a bit like an automatic flushing toilet, and it simply contracts and empties again. So we wanted to fill the bladder faster than its physiological rate, which is about 1 ml per minute per kidney, but not so fast that it emptied too rapidly. So in the sluice room, in the X-ray department – we had it stacked up with crates of beer – and all these paraplegics that we had on the X-ray table were given beer to drink. Can you imagine getting that on a research grant now? But the end result was that we discovered that the problem was that the external urethral sphincter in these patients was contracting at the same time as the bladder was contracting, so that the bladder couldn't empty. The solution clearly was to do a transurethral section of that sphincter, in fact make the patient incontinent, because that would stop the reflux to the kidney. That piece of research completely changed the management of paraplegic patients. From that time on, paraplegics did not die of kidney failure. So I think that's one area where instrumentation has had a big effect on patient management.

The second area, which Peter [Wells], I suspect, knows more about than I do, is the area of Doppler ultrasound. In the early 1970s if you had a carotid angiogram – to look at deposits within the carotid arteries – the morbidity and the mortality for that procedure was 2 or 3 per cent. One of the drivers for developing Doppler ultrasound techniques for measurement of blood flow – sorry, I should have said that Roland [Blackwell] probably knows more about this than I do, as well – was to reduce that morbidity and mortality in carotid angiograms. There were a number of groups in the UK working on this. Two people who immediately come to mind are John Woodcock and Colin Roberts.[197] It was necessary at that stage to build all our own ultrasound equipment, and I can remember designing and building bi-directional Doppler equipment. I designed an extremely high-speed frequency analyser, so that we could look at the waveforms, and so on. But you all know what the net result of that is, nobody would now dream of doing a carotid angiogram, and of course it developed much further than that, in that we now have colour flow imaging techniques which can give us very good detail.[198]

West: I wanted to add briefly to the comments about the changes in the applications of physics and engineering to medicine. At the University of California in San Diego, where I work, one of the most rapidly growing departments is the department of bioengineering. You may say, 'Well, what are all these graduates doing?' The answer is they are going out into industry, in the biotechnology industry, and if you want to know what they make, just go to any big meeting of cardiologists or pulmonary physicians, and look at the exhibition. There is an enormous growth in medical technology, and so this is an indication of the way physics and engineering have changed in relation to medicine.

Newing: Can I change the subject a bit and talk about ultraviolet, which is another much more recent area? In the early 1970s, a treatment came in for psoriasis, vitiligo and various skin diseases, called PUVA, which was psoralens with ultraviolet A. Most dermatologists bought a commercial irradiator and allowed their nurses to treat the patients. The nurses treated the patients either until they thought they were done, or by some timer. We were extremely lucky in Gloucester in that, at the time, the late 1970s, we had an extremely enlightened dermatologist, who decided that it would be rather nice if the physics department set up a PUVA service. I had been brought up as an ionizing radiation physicist who regularly calibrated machines, and measured things

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[197] Professor Rod Smallwood wrote: 'John Woodcock is Professor and Head of Department in Cardiff, and Colin Roberts was Professor and Head of Department at Kings' College Hospital, London, and a former President of the Biological Engineering Society, which merged with the Hospital Physicists' Association.' E-mail to Dr Daphne Christie, 11 July 2006. See McCarty and Woodcock (1974); Woodcock (1980); Horrocks *et al.* (1979).

[198] See, for example, Sumner (1990).

like beam flatness and so on, so we approached this from the physics point of view. We built our own irradiators, and our first body irradiator had parabolic reflectors, because we decided that at a certain distance in front of the parabolic reflectors we got more or less parallel beams. We had an old X-ray tube stand and we mounted our irradiator which had five horizontal tubes with their parabolic reflectors and three vertical ones with their parabolic reflectors, and we used to bring it down to a certain distance above the patient, who was also the right distance from the lateral irradiators, so we treated the front and one side, and then the patient turned over and we treated the back and the other side. We used to measure weekly flatness and output. Also we were lucky enough to acquire a spectroradiometer, so that we could see exactly what wavelengths we were using for treatment. We did all sorts of other things, like we decided that it was necessary when one tube went in the array, to replace all the tubes. The practice had been to put in one new tube, which turned out to have a much higher output than all the others, and all these sorts of things. We were rather on our own, with the exception of people like Brian Diffey, who at that time was in Canterbury.[199] He also had a spectroradiometer and then he moved to Durham and there was another one, and so there were three in the country at that time, and then another one in London, so that we could do a certain amount of comparison. I was delighted to find that this paved the way to the dosimetry that I felt we ought to provide for ultraviolet, and that has progressed very much in recent years.

Thomas: I suppose in terms of X-ray technology the single most important thing that has happened in this period, since Röntgen originally discovered X-rays, has been the EMI scanner, which was a CT scanner, which we mentioned in passing.[200] I suppose coming out has been digital technology and what CT brought in was looking at the body in a very different way, in a series of cross-sectional slices, rather than a two-dimensional projection of a three-dimensional structure, and it has really been digital technology that has fundamentally driven medical imaging. I suppose now with the powers of computing, it has also been how images have been produced, so in the more recent times it has

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[199] Professor Brian Diffey FInstP FIPEM, is Honorary Professor, Clinical Laboratory Sciences, University of Newcastle upon Tyne and Head, Department of Medical Physics, Clinical Director, Regional Medical Physics Department, Newcastle upon Tyne Hospitals NHS Trust.

[200] Hounsfield (1973); Ambrose (1973); Perry and Bridges (1973). See also Tansey and Christie (2000):12, 13, 20, 22, 28. Freely available online following the links to Publications from www.ucl.ac.uk/histmed.

been the application of digital technology to CT and from that to nuclear medicine, to ultrasound, and all aspects of what we are doing. All imaging (equipment that is currently being installed) is now digital, which is obviously a significant triumph and a change introduced by medical physicists and by the computer industry.

Jennings: A very quick point about dosimetry. I went from NPL to Teddington Hospital for some heat treatment on my shoulder, and I inquired about dosage out of interest, and they said, 'It would be three minutes', and, 'Oh, don't worry if it gets too hot, ring the hand bell which we will give you'. That was in about 1980. I felt that a little attention was needed for heat treatment.

Clifton: Yes, I think it is worth reflecting a little bit on the changes in medical physics in the sense that if you look back, up until about the 1960s medical physics departments were pretty much owned lock stock and barrel by radiotherapy. There were physicists in those departments who were doing isotope work, and this was an anomaly, because here you had a therapy department, and physicists working for a therapy department, actually providing a diagnostic service. But the point I want to make is that after 1960, or thereabouts, we started to see independent departments of medical physics. This enabled them, or the physicists within those departments, to apply their skills and their interests to clinical disciplines other than radiotherapy. If you were in a large teaching hospital, or a district general hospital, then you had the opportunity to work with other clinicians. This leads one to reflect on the fact that a lot of what one does in medical physics, in fact, is a bit of serendipity. Now if I look back to 1962, at that time hyperbaric oxygen was all the rage for radiotherapy treatment, because of the work that had been done at Mount Vernon by Harold Gray, and Jack Fowler, of course, was there. At UCH we had a hyperbaric oxygen tank, developed by Vickers Aircraft, with a pressurization system designed for their aircraft, to pressurize it, and we needed to measure the tissue oxygen tension. So we applied and got a grant to develop a transducer for measuring tissue oxygen. It was based on the concept that we could do this by looking at the oxygen effect on semiconductors. Needless to say, it didn't work, but from that work, subsequently, we developed the oxygen catheter. An intra arterial oxygen catheter that was used in the neonatal department and revolutionized the control of cerebral oxygenation of newborn infants. This was a classic example of something that didn't work in one area, but because of the range of interests that the department had, it had been taken to another area, with

Figure 17: Model of the Hunslet Rotating Cobalt Unit with Vickers Hyperbaric Oxygen Chamber. Professor John Clifton wrote: 'I am demonstrating the system to Sir Henry Dale of the Wellcome Trust. *c*. 1962. The man behind me is Dr Himsworth, Chairman of the UCH Medical Committee at that time. The photograph was given to me at that time.' Note to Dr Daphne Christie, 12 May 2006.

Figure 18: The first system for continuous monitoring of arterial oxygen levels in sick newborn babies. Developed in the Department of Medical Physics and Bioengineering, UCL, and originally marketed by G D Searle and Co. Ltd, High Wycombe, UK. Professor Dave Delpy wrote: 'The slide was one that G D Searle produced. Searle sold the company to Orange Medical who were then bought by Biomedical Sensors, who were then bought by Pfizer and, following a period as a management buyout, they were purchased by Diametrics Medical Ltd. All the sensors that are now sold are totally different.' E-mail to Professor John Clifton, 12 May 2006.

another physician who was very interested, and it went on from there. David Delpy can tell you, no doubt, a great deal about all the other developments that followed on from that.

Ashton: I want to pick up on what John [Clifton] was saying about medical physics becoming an independent department. In Yorkshire, in 1960, with some foresight perhaps, we had a regional medical physics service, which in fact was independent of any hospital, as well as of any clinician.

Smallwood: Just a rider on what John [Clifton] said. Our development of Doppler blood flow measuring equipment was originally for looking at a completely different problem. So again, it was serendipity that we had actually developed the equipment for a problem that other people came along to us with.

Wells: Here is another anecdote about the Doppler and the good old days. It was in about 1970 that we thought that it might be possible to detect tumour angiogenesis using the Doppler effect, and I remember saying to my colleagues, 'Is this a possibility?' They said, 'Oh, probably', and went on drinking their tea. It was exasperating. So I grabbed one of these Doppler machines, rushed off to the ward, and I said to the sister, 'Is there any chance that you have a lady here with breast cancer who wouldn't mind me just trying something?' And sister said, 'Yes, that lady over there'. So I went over and I asked, 'Would you mind if I just popped this probe on your breast?' And she said, 'No, that's all right'. I popped it on and lo-and-behold that was how the Doppler signal from tumour neovascularization was discovered.[201] I bet it would be more difficult nowadays.

Williams: One observation I would make about the last few comments is that a lot of the people who have spoken have given anecdotes about things they have done, and not necessarily in the field that we know them for. What worries me a little bit is that 20, 30 years ago, people were allowed to dabble in lots of different things. So, for example, if I have done anything useful in the last ten or 15 years, it's been radiotherapy stuff. But I spent some time in the 1970s investigating a sphincter, a little bit posterior to the one that Rod was describing, with some very simple instrumentation. Similarly, the first job I was given was a bit of instrumentation to measure oxygen tension for a radiotherapy

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[201] See, for example, Wells *et al.* (1977).

problem, when neutrons were being used as an alternative solution to the oxygen hypoxia problem. I wonder now, as medical physics has developed and become specialized, whether the people that are in our position in ten years' time will be able to apply their skills in more than their specialized areas. That is quite scary.

Haggith: Just to add to what Tom had to say about regional departments. I think the regional departments, which have been advocated from the very beginning because they can make scarce resources available to many hospitals, came about from the Radium Commission, which said that the Radium Centres were to provide a service to their region. So I think you have, certainly outside of London, these large regional departments that have been successful.

Williams: Certainly the department in Manchester was part of the radiotherapy department until 1969, because I remember being invited to a party about three weeks after starting. It wasn't a very big party, because at that point there were only eight physicists in the department, and Jack Meredith was celebrating the fact that he had been released from the control of radiotherapists – but willingly. A lot of the radiotherapy departments that owned physics departments in the 1950s and 1960s were relatively enlightened and they saw the benefits of physics departments becoming independent and serving other masters.

Burns: There is one thing that I don't think has been commented on so far. When I came into medical physics in 1953, the qualification required was an honours degree in physics. It was quite clear that medical physics technicians and biological engineers were kept at arm's length. Now in subsequent years these have come together, and I think this can only be applauded. This is very much to the benefit of medical physics. On the other hand, it seems that things have moved in the opposite direction in another sense, in that there are now the requirements for state registration. I know these things keep on changing, but it has become more and more difficult to recruit senior people into medical physics at a salary that would attract them. All these requirements and qualifications came to a head when I read a recent advertisement, 'Successful candidates will be asked to apply for an enhanced disclosure from the Criminal Records Bureau'. I can't imagine quite what's next.

Williams: That latter point is nothing to do with medical physics, it is to do with the health service as a whole. I think the concept of state registration for healthcare scientists is hard to argue against, because state registration is there to protect the public and we do things that are potentially quite dangerous, and, sadly, over the years medical physicists have been involved with fairly high-profile incidents, where things have gone wrong, and whereas our medical colleagues tend to do damage to one patient at a time, we tend to do it in great groups of patients. So state registration is a nuisance, and in particular in bringing expertise in from different sectors, but it is a lot easier in big departments than in small departments. If you have a department of three people, having one person that's not state registered is a huge problem. If you have a department of 30 people, then letting that senior, well-paid person practise with modest supervision is legal and possible.

Now, one of the themes in the programme today is the link with industry, academic and undergraduate medical physics. I wonder if we have something to say about that.

Clifton: It is worth looking back a little bit at the history of the development of, if you like, academic and undergraduate medical physics in the last 20 years. Back in the late 1970s, the medical curriculum was revised, and as a result of that revision, the need for teaching first and second MB [exam for the Bachelor of Medicine] physics was removed, and this basically removed the rationale for academic medical physics departments in medical schools. When this was then coupled with the inevitable retrenchment in costs, and reorganization of funding, we saw in the beginning of the 1980s the disappearance, certainly in London, of a number of chairs of medical physics. People began to think that academic medical physics was about to disappear altogether. On the other hand, at the same time, physics itself was going through a difficult period, and Angela has referred to it still being in existence, that physics was no longer seen as a viable career. High-energy particle physics was looked upon as very expensive and apparently going nowhere, chasing more and more abstruse particles. Physicists going into the armament industry were not particularly acceptable. So you started to see physics departments saying, 'Look, where have we got an acceptable face of physics?' The result was that in the early 1980s, we started to see courses appearing, undergraduate courses now, of physics with medical physics, and electronics with medical electronics, and some departments even producing a BSc in medical physics. This meant that, effectively, what had been academic medical physics for medical people was now academic medical physics for the patient. What we were talking about was applied physics for the benefit of the patient. That resulted subsequently, with the emphasis on there being a clear outcome of research, of what had previously been seen as rather less acceptable research because it was applied, now becoming very acceptable. In the last decade we have seen the numbers of chairs of medical physics increase quite dramatically;[202] also with medical schools now associated with multiple disciplinary academic colleges, medical physics is developing quite rapidly in a number of areas, with a great deal more academic standing than it had before and medical physics departments, not in the Faculty of Medicine as they were, but in the Faculty of Science.

Booth: The result of what you have described is not a question just facing physics. The whole problem has been the introduction of what they call the integrated course and the destruction for medical students of preclinical training. It means that medical students no longer study botany, they do a little bit of zoology, but not very much, they know virtually nothing about evolution in theory, they don't do biochemistry or chemistry as a subject, and they don't do anatomy as a subject either. They do a clinical course in which they are introduced to the clinical teaching in the first year. Universities have been responsible for this disaster: McMaster in Canada, Newcastle (New South Wales) and Maastricht in Holland. They have introduced these integrated courses that now have been taken on by Harvard, for example. Half the stream in Harvard goes for an integrated course, and it means that doctors no longer get a proper training at all, at university level. I think that has been a disaster.

Williams: There seems to be general agreement that it is not a good thing. What we have heard this afternoon have been a lot of interesting memories, identifying the fact that physics and engineering have made huge contributions to medicine over the years. Whichever generation we are in, we always think that we have nearly finished and there's not much more to do. My guess is that is wrong, that there is a lot to do. One of the privileges I had during the last couple of years was going to the Royal College of Physicians' Harveian Oration. It's an annual oration that takes place at the Royal College of Physicians, followed by an excellent dinner. Two years ago we had Paul Maer, a Nobel Laureate, speaking to us and towards the end of his lecture, not knowing there were any physicists in the audience, he pointed out that biology was now getting so complicated

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[202] Professor John Clifton wrote: 'A head count of the IPEM membership list for 2006 gives 122 professors in the UK. This list will include some who are professors of bioengineering. Given that there were probably not more than 20 such professors in the 1980s the growth is remarkable. There may also be others who are not members of the IPEM.' E-mail to Dr Daphne Christie, 27 September 2006.

that it needed physicists, engineers and mathematicians to help them sort out the difficult concepts that they were having to deal with, because biologists, he confessed, were only any good at counting hairs on beetle's legs; they weren't very good at concepts. I think he was right. He was talking about physics and engineering, not just to make bits of kit, not just to make instruments to measure things, but getting to understand the biology and the physiology that is going on inside human beings and other organisms. So I think there is a lot of physics applied to medicine and biology to do yet, and maybe if the Wellcome Trust's History of Twentieth Century Medicine Group is still going in 20 years, there will be another group of people, maybe some of you will still be here. And there will be another round of recollections. So I would like to thank you for coming, for your contributions and for your memories. Nothing too scurrilous has been said yet, but the next part of the agenda is to share a drink of wine and have a more informal chat, which I promise will not be recorded, so that's the time for the scurrilous stuff. Thank you.

Tansey: May I also add my thanks, on behalf of the Wellcome Trust Centre, to you all for coming and sharing your comments and your memories with us. Not only a lot of physics, but a lot of history of medical physics. I think it is quite clear, and I hope we don't have to wait 20 years before there's a further meeting, because there is a lot that has gone on today that could generate another meeting. So perhaps one of the bodies that is represented here today might think of trying to develop a Witness Seminar either on your own or in collaboration with us. So thank you all very much for coming and, Peter, thank you for excellent chairing. Please do join us now for a glass of wine.

Appendix 1

Additional communication[203]

Dr Lloyd Kemp, 13 May 2005

The first consequence of addressing myself to the task of making this contribution to the Witness Seminar took me by surprise: it was to see my own career in medical physics in its proper historical perspective, perhaps for the first time. I was a young man still in my 20s when I took up my first post in medical physics as assistant to Dr John Read, head of the physics department at The London Hospital. X-rays, beta rays, gamma rays and radioactivity seemed to have been around for donkey's years, and Röntgen, Becquerel, Sir J J Thomson, Marie Curie and the like, revered pioneers of long, long ago – in fact, two of my lifetimes, as of then. From the perspective of my 91st year, however, I look to have been quite early on the scene: for a present-day newcomer to medical physics, it would be as though all those discoveries, absolutely fundamental to the profession they were joining, *had been made as recently as the 1960s!*

Nowadays, innovations in this field are more often than not of necessity the outcome of teamwork, often industrially based, and involving the expenditure of very large sums of money. But that only serves to put those earlier days in still better perspective. The early pioneers I've mentioned worked as individual scientists, ferreting out answers to questions that they had raised for themselves; the story of Marie Curie's personal and heroic doggedness which led to the isolation of radium being, indeed, legendary. Furthermore, I can see now, looking back, that I myself was fortunate enough, and, indeed, *privileged,* so far as the actual research and development work I undertook was concerned, to be able largely to follow my own instincts and intuition as to the particular wheel to which I should put my shoulder, so to speak. And the particular wheel I chose was precision dosimetry – particularly of the dose distribution in X-ray beams, and around linear arrays of radium needles, producing comprehensive sets of so-called 'isodose curves' for all the standard beam cross-sections and X-ray penetrating power, and linear arrays of radium needles, used in radiotherapy.

The X-ray dose distributions were measured in a tank of water (known as a 'water phantom') representing body tissues, and had previously been graphically

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[203] Dr Lloyd Kemp was unable to attend the Witness Seminar held on 5 July 2005. The following piece was prepared for the seminar.

interpolated from individual measurements made at a mesh of discrete points in the water phantom, a process taking many hours, amounting to a day or so's work, per X-ray beam applicator.

The necessity for this laborious procedure was brought to an end by my automatic dose plotter, by means of which the small ionization chamber serving as a probe could be set to follow and plot any given isodose curve, expressed as a percentage of the surface X-ray dose, each curve taking around ten minutes only to plot, and a complete set of isodose curves for a given applicator about one-and-a-half hours, instead of around one-and-a-half working days. This machine enabled many more comprehensive sets of isodose curves to become available, including those representing the asymmetrical X-ray beams produced by the so-called 'wedge' filters devised by Dr Frank Ellis for the treatment of special tumour sites, such as the thyroid.

The automatic dose plotter was based on a so-called 'X-ray Intensity Comparator', the development of which had preceded it, and it was realized that this instrument could also be used to break new ground in the realm of medical physics, namely in the diagnostic X-ray department, where it was used to demonstrate that uncertainties in the quality of radiographs were associated with cross-beam variations in the intensity and penetration of the X-ray beam, leading to various improvements in radiographic techniques.

Alongside these developments in the measurement techniques of the properties of X-ray beams, I was developing new instrumental techniques for the computation of dose distributions around linear arrays of radium needles, in particular those used in the treatment of cervical cancer. The prototype of these instruments was, in fact, literally built at home, on the kitchen table, before I had obtained my first salaried post as a medical physicist. No – it wasn't built of sealing wax and string, but it was tantamount to that; built, in effect, by what one would have to call an amateur medical physicist, while he was still teaching physics at Bradford Grammar School! That earliest model took no account of the increased absorption of the gamma rays as they passed more and more obliquely through the platinum walls of the containing tube in acutely angled directions, but the final version certainly did, and was exhibited in 1949 at the Annual Exhibition of Scientific Instruments under the auspices of the Institute of Physics. By an extraordinary coincidence I found myself next to one Colin Cherry, with whom I had worked ten years before in the Research Labs of the GEC. By 1949 he had become Professor of Cybernetics at Imperial College, and it was he who informed me – actually to my great surprise – that what I had devised was in fact quite a sophisticated analogue computer! It was news to me.

During the next few years I moved on from clinical dosimetry to the fundamentals, and something prompted me to suspect that all was not well with the two most important national standards of radiation dose: the one held at the National Physical Laboratory (NPL) in the UK, and the other at the National Bureau of Standards (NBS) in Washington, in the USA. There had been an international intercomparison of the two standards, and they had been found to agree to within 1 per cent – considered to be a very satisfactory state of affairs, especially as the two standards had by no means identical design features. My research was protracted and painstaking. Imagine the situation when I came to the conclusion that whilst *agreeing* to within 1 per cent, the two standards were *both* in error – approaching 2 per cent in the American case, and 3 per cent in the UK case. Imagine, too, the trepidation with which I presented these results in a paper read at the International Conference held in Copenhagen, in 1954. How would those in charge of the two standards respond? I needn't have worried. Dr L S Taylor, of the NBS, who was sitting at the back of the conference hall, followed the end of my presentation with an immediate comment. 'Well,' he said, 'it only goes ter show that if yer sittin' on the fence, you ain't necessarily sittin' pretty.'

It seemed almost natural that, after a further ten years in medical physics, I moved on to take charge of the low- and medium-energy dosimetry group at the NPL. There, during the last 12 years of my working life, I supervised the development of a new X-ray secondary standard, which is still in use in hospitals. The special design features incorporated in this instrument resulted in its calibration factors showing no long-term systematic changes over a period of time measured in decades. It seemed a fitting note on which to end a career devoted to precision in X-ray dosimetry.

One last comment: I retired in 1978, and during my 12 years at the NPL it had seemed very much like working on a university campus. I was fortunate, for very shortly after that, much of the work came under the management of external committees, and intellectual freedom and spontaneity has, I believe, become increasingly inhibited. But there, such changes have not been limited to the NPL, and looking back, it seems as though I might have been one of the last of the old breed of scientists, who enjoyed the privilege of being able to work with something approaching the freedom of the creative writer, artist or musician.

Appendix 2

Funding for Medical Physics in the UK in the 1950s and 1960s

Mr Bob Burns, 10 January 2006[204]

There was one aspect of medical physics in the UK that was not mentioned in the Witness Seminar in July 2005, and that was how it was funded. A little knowledge of this helps to explain how the profession expanded in the 1950s and 1960s.

When the NHS took over in 1948 it first shut down tiny unviable radiotherapy departments. Then it made funds available to ensure that each of the remaining 70 or so had access to physics assistance on a regular basis, initially at least one day a week. This provided a secure foundation for the development of medical physics.

Once the basic staff and facilities were in place, they began to attract substantial funds from the Medical Research Council (MRC) and the British Empire Cancer Campaign (BECC). These funds were sufficient to provide not only equipment and supplies, but also physicists and supporting staff, and even accommodation, and were intended for applied research and development.

It was this combination of funds that enabled medical physics in the UK to expand and diversify so that by the 1960s physicists from all over the world came here to learn more about the work. Some of these came individually (occasionally funded by the British Council), but in the mid-1960s there were two separate six-month intensive courses for trainee medical physicists from the developing countries.

Although the courses were initiated and entirely funded by the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO), the detailed arrangements in the UK were organized by the Hospital Physicists' Association (HPA). There were about 16 members on each course, if I remember correctly. Members in pairs were based at each of the largest hospital physics departments for on-the-job training, which was supplemented by organized lectures and brief visits to other hospitals and research laboratories to widen their experience. It was remarked at the time that they were given a better organized and more comprehensive training than any individual British hospital physicist had received!

I have no idea about how the subsequent expansion of medical physics was funded, because I left it in 1968.

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[204] Letter to Dr Daphne Christie from Mr Bob Burns, after the Witness Seminar had taken place, 10 January 2006.

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Biographical notes*

Edgar Douglas Adrian, Baron Adrian of Cambridge
FRCP FRS (1889–1977) was Vice-Chancellor (1957–9) and Chancellor, University of Cambridge (1968–75), Professor of Physiology at the University of Cambridge (1937–51), Master of Trinity College, Cambridge (1951–65), President (1955–7) and Chancellor (1957–71) of the University College of Leicester, President of the British Association for the Advancement of Science in 1954 and of the Royal Society of Medicine (1960–1). For his work about the functions of neurones Adrian was awarded, jointly with Sir Charles Sherrington, the Nobel Prize in Physiology or Medicine, 1932. See http://nobelprize.org/nobel_prizes/medicine/laureates/1932/adrian-bio.html (visited 27 September). See also Hodgkin (1979).

Mr Tom Ashton
FInstP (b. 1928) graduated in physics and electrical engineering in 1950 from the University of Leeds, was Physicist in Medical Physics at the Christie Hospital, Manchester, and Cookridge Hospital, Leeds (1951–64), Visiting Professor, Upstate Medical Centre, State University of New York in 1962, head of the Regional Centre, MRC/National Radiological Protection Board (1964–73), Secretary of the ICRP Task Group: Revision of ICRP 5 (1971–3), and Regional Scientific Officer, Yorkshire Health Authority (1973–92).

Dr Barry Barber
(b. 1933) was appointed medical physicist at the Royal London Hospital in 1954 and worked with Dr Lloyd Kemp on precision dosimetry, gaining a PhD in 1960. He was involved in the uses of the hospital's Elliott 803 computer prior to and following its installation in 1964. He became Director of the newly created Operational Research Unit at the hospital in 1966 and a member of the project executive for the Hospital's real-time experimental computer project initiated in 1968. He was transferred to the North East Thames Regional Health Authority as Chief Management Scientist following the 1974 NHS reorganization to support the regional health authority's

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* Contributors are asked to supply details; other entries are compiled from conventional biographical sources.

strategic planning process with statistical and operational research techniques, and was seconded to the NHS Executive in 1988 as manager of the security and data protection programme. He was the first Chairman of the Computer Topic Group and retired in 1997, after 42 years in the NHS, to undertake a variety of EU and standardization projects.

Antoine Henri Becquerel (1852–1908), for his discovery of spontaneous radioactivity Becquerel was awarded half of the Nobel Prize for Physics in 1903, the other half being given to Pierre and Marie Curie for their study of the Becquerel radiation. He was elected a member of the Academie des Sciences de France in 1889 and succeeded Berthelot as Life Secretary of that body. He was made an Officer of the Legion of Honour in 1900. See http://nobelprize.org/nobel_prizes/physics/laureates/1903/becquerel-bio.html (visited 19 September 2006).

Professor Roland Blackwell FIEE FInstP FIPEM (b. 1943) has been at UCL since 1966 and is currently Head of the NHS Department of Medical Physics and Bioengineering.

Dr Joseph (Nat) Blau FRCP FRCPath (b. 1928) was consultant neurologist at the National Hospital for Neurology and Neurosurgery, Queen Square, London (1962–93), the Royal National Throat, Nose and Ear Hospital, London, (1968–93) and Northwick Park Hospital, Harrow (1970–93). He retains an interest in migraine and other headaches and continues practising as Honorary Director and Honorary Consultant Neurologist at the City of London Migraine Clinic, Smithfield, which he and Dr Marcia Wilkinson founded in 1980.

Professor John Wilson (Jack) Boag FInstP FIEE FRStatSoc (b. 1911) was Professor of Physics as Applied to Medicine, Institute of Cancer Research, University of London, from 1965 to 1976, now Emeritus. He was Physicist, Medical Research Council (1941–52), British Empire Cancer Campaign, Mount Vernon Hospital, London (1953–64), President of the HPA in 1959, the Association for Radiation Research (UK) (1972–4), the International Association for Radiation Research (1970–74), and the British Institute of Radiology (1975–6).

Sir Christopher Booth
Kt FRCP (b. 1924) trained as a gastroenterologist and was the first Convenor of the Wellcome Trust's History of Twentieth Century Medicine Group, from 1990 to 1996, and Harveian Librarian at the Royal College of Physicians from 1989 to 1997. He was Professor of Medicine at the Royal Postgraduate Medical School, Hammersmith Hospital, London, from 1966 to 1977 and Director of the Medical Research Council's Clinical Research Centre, Northwick Park Hospital, Harrow, from 1978 to 1988.

Professor Terence Burlin
(b. 1931) was Physicist at the Mount Vernon Hospital (1954–7), the Hammersmith Hospital, London (1957–62) and joined the University of Westminster, (1962–95), where he was appointed Physicist in 1962, Reader in 1982 and Rector (1982–95). He was Chairman of the British Committee on Radiation Units and Measurements (1984–93) and Chairman, ICRU Committee on Practical Determination of Dose Equivalent (1979–87).

Mr J E (Bob) Burns
(b. 1928), following several years in the Meteorological Office, was a medical physicist at various hospitals between 1953 and 1968. During his subsequent career at the NPL in Teddington, he developed and inaugurated a calibration service for secondary-standard radiation dosemeters in terms of absorbed dose-to-water, based on a primary standard graphite calorimeter in megavoltage X-ray beams – the first such service in the world.

Professor John Cameron
(1922–2005), Professor Emeritus of Medical Physics at the University of Wisconsin, where he had the founding Chair of the Department of Medical Physics, and was charter member and Past President of the American Association of Physicists in Medicine. He completed a doctorate in physics at the University of Wisconsin in 1952 under Professor Ray Herb, inventor of the tandem Van de Graaff and founder of the National Electrostatics Corporation. After junior staff appointments at the Universidad de São Paulo and the University of Pittsburgh, he returned to Wisconsin in 1958, with a joint appointment in physics and radiology. His Department of Medical Physics was created in 1981, the first such department in the USA. Cameron's contributions to medical physics included a trans-illumination device for diagnosis of hydrocephalus, a bone mineral absorption device, thermoluminescence dosimetry,

the Ardran–Crookes 'Wisconsin' test cassette, and his lifelong commitment to quality assurance in radiology. See Goetsch (2005).

James (Jim) Clarkson
FInstP (b. 1908) was Radon Laboratory Technician at Birmingham University, making radon seeds for many hospitals in the Midlands (1931–7), Assistant Physicist at the Royal Cancer Hospital (1937–44), Physicist at the Royal South Hants Hospital, Southampton (1944–62) and Regional Physicist to the Wessex Regional Hospital Board (1962–73). He was President of the HPA between 1953 and 1954.

Professor John Clifton
FInstP FIPEM (b. 1930) graduated from the University of Southampton in 1955 and started a career in medical radiation physics at the Royal South Hants Hospital, Southampton. He moved to the University College Hospital Medical School (UCHMS) medical physics department in 1957 and was appointed head of the department in 1962. Following the merger of UCHMS with UCL in 1981, he was appointed Professor of Medical Physics there, and Joel Professor of Physics Applied to Medicine in the University of London in 1990, now Emeritus. He was President of the Hospital Physicists' Association (now the Institute of Physics and Engineering in Medicine) from 1976 to 1978, Honorary Editor of *Physics in Medicine and Biology* from 1979 to 1983. He initiated the formation of the European Federation of Organizations for Medical Physics (EFOMP) in 1978, and was the first President of the Federation from 1980 to 1984.

Dr Philip Dendy
(b. 1938) trained in radiobiology in the Department of Radiotherapeutics, University of Cambridge and was subsequently Senior Assistant in Research (1966) and Assistant Director of Research (1970). In 1975 he moved to the Department of Medical Physics, University of Aberdeen, as Senior Lecturer, later Reader, returning to Addenbrooke's Hospital, Cambridge, as Chief Physicist in 1983. He was President of the Institute of Physical Sciences and Medicine from 1992 to 1994.

Professor Frank Farmer
OBE FInstP FIEE (1912–2004), was assistant physicist in 1940 in the radiotherapy department at the Middlesex Hospital, London, and while there designed the Farmer dosemeter [Farmer (1955)], which became a standard instrument for calibrating X-ray machines in radiotherapy departments across the

world. In 1945 he was appointed Physicist to the Royal Victoria Infirmary, Newcastle upon Tyne, where with C J L Thurgar, the chief radiotherapist, he built up a radiotherapy service in the northern region. Frank helped pioneer the design of a linear accelerator for cancer treatment, which was installed in the Newcastle department in 1963. It produced X-rays of high energy (up to 4 meV), which could treat deep tumours while avoiding the severe skin damage of earlier treatment. In 1950, his research was in the clinical uses of radioisotopes and the radioisotope tracer technique. He was appointed Professor of Medical Physics at Newcastle University in 1966, and was President of the HPA (1959–60), and of the British Institute of Radiology (1973–4). See *Times Obituary,* 10 September, 2004.

Professor Jack Fowler
(b. 1925) was Reader in Medical Physics to Professor Sir Joseph Rotblat, St Bartholomew's Hospital, London (1962–3); Head of Physics Section in the MRC Radiotherapeutic Research Unit, Hammersmith Hospital, London, in 1959 (later the Cyclotron Unit; Professor of Medical Physics, the Royal Postgraduate Medical School, Hammersmith, London (1963–70), Director of the CRC Gray Laboratory, Mount Vernon (1970–88) and Professor of Human Oncology and Medical Physics, University of Wisconsin, Madison, USA (1988–94).

Dr Herbert Freundlich
(1909–94) worked with Murphy Radio in the UK, on the UK Atomic Energy Project in Montreal and with Professor Joe Mitchell in the Department of Radiotherapeutics, Cambridge. He developed an interest in hospital physics here and played an important part in the development of an iridium-192 teletherapy unit, which could deliver equivalent treatments to those of a radium 'bomb'. In 1951 he was appointed Head of the Medical Physics Department at Bristol where one of his first projects was the introduction of a cobalt unit designed in Bristol and built in Cambridge, the first British-built cobalt unit in the UK. He was President of the HPA from 1973–4.

Louis Harold Gray
FRS (1905–65) worked at the Cavendish Laboratory, Cambridge (1927–32), on the absorption of gamma rays in matter. He went to Mount Vernon Hospital in 1933 and with John Read, built the first neutron generator for radiobiology in a wooden hut. In 1947 he was appointed to the MRC

Radiotherapeutic Research Unit at Hammersmith Hospital to develop radiobiology and radioisotope research, and in 1953 returned to Mount Vernon to found the Gray Laboratory. He was Chairman of the HPA from 1946 to 1947. See Boag (1965); *Times Obituary,* 13 July, 1965.

Dr Jean Guy
(b. 1941) qualified in medicine in 1966 and practised as a diagnostic radiologist with a special interest in scintigraphy (radioisotope imaging). She worked as a consultant in Wales, Somerset, Shropshire and Suffolk and retired in 2001. Her MD topic was 'The History of Radiology in Britain, 1896–1921'.

Mr John Haggith
FIPEM (b. 1930) was appointed Physicist at Newcastle upon Tyne in 1957. Apart from a year at the Stanford Medical Centre, California, commissioning the first Varian Clinic, he remained in Newcastle as Head of the radioisotope section of the Northern Regional Medical Physics Department and latterly as deputy head of department until his retirement in 1992. As chairman of the HPA's Publications Committee he compiled the *History of the Hospital Physicists' Association, 1943–1983* [Haggith (ed.) 1983)] and is at present editing a multi-author booklet bringing this up to date.

Dr John Haybittle
(b. 1922) was appointed junior physicist at Addenbrooke's Hospital, Cambridge, in 1948 and retired from there as Chief Physicist in 1982. He was Secretary of the BIR from 1962 to 1967, Editor of the *British Journal of Radiology* from 1981 to 1986, received the Röntgen Prize (BIR) in 1972 and the Barclay Medal (BIR) in 1987.

Professor Frank Lloyd Hopwood
FInstP (1884–1954) was Demonstrator and Lecturer in Physics, St Bartholomew's Hospital (1906–20), Physicist (1920–49) and Professor (1924–49). He was a President and Silvanus Thompson Medalist of the BIR, a founder member of the British Empire Cancer Campaign and the Institute of Physics as well as the HPA. See Haggith (ed.) (1983): 102.

Professor Sir Godfrey Hounsfield
FRS (1919–2004) was head of Medical Systems at Thorn EMI from 1972 to 1976 and was consultant to Thorn EMI Central Research Laboratories from 1986. In 1969 he invented the EMI Scanner (computerized transverse axial tomography system) for X-ray examination, which revolutionized X-ray diagnosis and for which

he received the Nobel Prize in Physiology or Medicine in 1979. See http://nobelprize.org/nobel_prizes/medicine/laureates/1979/hounsfield-autobio.html (visited 20 July 2006).

Dr William Alan Jennings
FInstP FIPEM FRSP (b. 1923) spent the first half of his career as a hospital physicist (1942–67) initially under Sidney Russ. In the 1960s, with Anthony Green, he developed conformal radiotherapy at the Royal Northern Hospital, London. He was a founder member of the HPA and became its President (1966–7). He spent the second half of his career at the NPL, initially as Head of Radiation Dosimetry (1967–75) and later as Head of the Division of Radiation Science and Acoustics (1975–83). He was much involved in national and international work in the measurement of ionizing radiation.

Dr Harold Elford Johns
(1915–98), a Canadian medical physicist, worked on the use of ionizing radiation to treat cancer. After the close of the war, he worked with Ertle Harrington at the University of Saskatchewan in Saskatoon. He conducted his pioneering research in the use of cobalt-60 as a gamma ray source for the radiation treatment of cancer. Two groups – Johns' at the University of Saskatchewan and another in London, Ontario – designed and constructed external beam radiotherapy instruments using cobalt sources. Ultimately, the first treatment was delivered in London, Ontario, on 27 October 1951. See, for example, http://en.wikipedia.org/wiki/Harold_E._Johns (visited 20 July 2006).

Dr Lloyd Kemp
OBE FInstP (b. 1914) after working on the earliest TV systems at the GEC, he joined Dr John Read in The London Hospital Physics Department in 1944, becoming head of the department in 1946 when Dr Read left. There he developed methods for the automatic exploration of X-ray dose distributions, and analogue computers for the calculation of gamma-ray dose distributions around linear radioactive source arrays; he also demonstrated the existence of significant errors in the British and American Röntgen standards, for which he received the Röntgen Award (BIR) in 1956. In 1966 he joined the NPL, taking charge of the Low and Medium Energy Dosimetry Group, where he developed a high-stability secondary standard X-ray dosemeter, receiving the OBE in 1977, and retiring in 1978.

Professor Leonard (Len) Frederick Lamerton
FInstP HonFRCPath (1915–99) was Director of the Institute of Cancer Research, London, from 1977 to 1980 and Professor of Biophysics as Applied to Medicine, University of London, from 1960 to 1980. He was President of the HPA (1957–8) and BIR (1961–2). See Wright (2000); Steel (2000).

Dr John Law
(b. 1935) followed his first degree at Birmingham with a PhD in atmospheric physics at the Cavendish Laboratory, Cambridge, before entering the NHS in 1961 in the research laboratories at the Christie Hospital, Manchester, where he worked on calorimetric and chemical dosimetry. Since 1965 he has been a senior lecturer at Edinburgh University from 1972, with responsibilities for diagnostic X-ray and radiotherapy physics, and the physics Quality Assurance for the Breast Cancer Screening Programme from 1987 until his retirement in 1995. He continues to pursue research interests in breast screening.

Professor John Mallard
OBE FRSE FREng (b. 1927) began medical physics in 1951 at the Liverpool Radium Institute and was at the Hammersmith Hospital, London, from 1953 to 1964. After a year at St Thomas' Hospital Medical School, London, he took the first Chair of Medical Physics in Scotland at the University of Aberdeen, and was Head of the joint university and NHS Department of Bio-medical Physics and Bio-engineering until 1992. In both London and Aberdeen, he created and led teams of physicists, engineers, technicians and students who built and used the equipment to pioneer nuclear medicine imaging and magnetic resonance imaging. He was President of the HPA (now IPEM) (1970–72); Founder Secretary-General, International Organization of Medical Physics (IOMP) (1961–5); Founder President, International Union of Physical and Engineering Sciences in Medicine (IUPESM) (1982–5); Commissioner, International Commission of Radiation Units and Measurement (ICRU) (1985–94), receiving several honours.

Professor Sir Peter Mansfield
FRS (b. 1933) has been Professor Emeritus of Physics, University of Nottingham, since 1994. In 1983 he was awarded the Gold Medal of the Society of Magnetic Resonance in Medicine and was its President (1987–88). He was created an Honorary Member of the Society of Magnetic Resonance Imaging in 1994, an Honorary Member of the BIR in 1993 and Honorary Fellow

of the Royal College of Radiologists in 1992. He received the Mullard Medal and Award, Royal Society (1990); ISMAR prize (1992); gold medal from the European Association of Radiology (1995); Rank Prize (1997) and the Nobel Prize in Physiology or Medicine (2003). See http://nobelprize.org/nobel_prizes/medicine/laureates/2003/mansfield-autobio.html (visited 20 July 2006).

Professor Valentine (Val) Mayneord
CBE FRS (1902–88) was Professor of Physics as Applied to Medicine (1940–64), and Physicist, Royal Cancer (later Royal Marsden) Hospital, London (1927–64). See Spiers (1991).

William John (Jack) Meredith
OBE FInstP (b. 1913) joined the physics staff at the Holt Radium Institute, Manchester in 1937 as assistant to H M Parker, and there worked on what became known as the 'Manchester Radium Dosage System'. Following Parker's departure to the USA in 1938 he became Senior Physicist and was head of the department for 34 years, after which he became the first Regional Administrative Scientific Officer to be appointed in the UK (to the North West Regional Health Authority). He received the Röntgen Award (BIR) for work with G J Neary for the calculation of X-ray isodose curves. He served on the HPA Executive Committee as Honorary Secretary/Treasurer and Chairman (1948–9) and was senior author of *Fundamental Physics of Radiology.*

Professor Joe McKie
(b. 1925) served as a physicist in the Lincolnshire Radiotherapy Centre (1947) and St Thomas' Hospital, London (1950), before moving to Dundee in 1953 where he founded the Regional Physics Department of the Scottish Eastern Regional Hospital Board. He moved to Glasgow as Deputy Regional Physicist to the Western Regional Hospital Board in 1964 and became Director of that department (now the West of Scotland Health Boards' Department of Clinical Physics and Bio-engineering) and Professor of Clinical Physics in the University of Glasgow from 1983 until his retirement in 1990.

Professor Harold Miller
OBE FInstP (1909–95) was appointed medical physicist to the Sheffield National Centre for Radiotherapy in 1942, where he was involved in the development of medical radiophysics in clinical work, later becoming Chief Physicist for the Independent Regional Department of Medical

Physics (1960–75). He became President of the HPA (1957–8), President of the BIR, and in 1972 Professor Associate of Medical Physics at the University of Sheffield. In the postwar world he took an interest in the development of medical services in the Third World, also playing a part in the Pugwash group of scientists who endeavoured to direct the use of atomic energy to peaceful objectives. See Haggith (1983): 116. See also NCUACS catalogue no: 92/5/00, 166pp, deposited in Sheffield University Library.

Professor Joseph (Joe) Mitchell CBE FRCP FRS (1909–87) was Regius Professor of Physic, University of Cambridge, from 1957 to 1975, later Emeritus, and Director of the Radiotherapeutic Centre, Addenbrooke's Hospital, Cambridge, from 1943 to 1976. See Marrian (1988).

Mr David J Murnaghan (b. 1938) was Physicist at St Agatha's Radiotherapy Clinic, Cork, from 1965 to 1971; and at the Institute for Industrial Research and Standard, Dublin, from 1972 to 1975; the National Radiation Monitoring Service, from 1975 to 1981; and at St Luke's Hospital, Dublin, from 1981 to 2003. He is currently a Member of Council of the Royal Dublin Society.

Professor Angela Newing FInstP FIPEM FIEE (b. 1938) began her career in medical physics at the Royal Sussex County Hospital, Brighton. She moved to Gloucestershire in 1966 and worked as a radiotherapy physicist at the Cheltenham General Hospital. Later she specialized in nonionizing radiation. In 1989 she became Director of Medical Physics for Gloucestershire, and retired in 1999. She has given much attention to the teaching of medical physics and continues to be Visiting Professor of Medical Physics in the University of Cranfield Postgraduate Medical School.

Dr Sidney Osborn FInstP (b. 1918) served as a Physicist for the King Edward Hospital Fund for London, from 1941 to 1942; at University College Hospital, London, from 1943 to 1962, and was Director of the Medical Physics Department, King's College Hospital and Medical School, London, from 1962 to 1978. He was a part-time Consultant to the WHO from 1962 to 1978 and served at various times on Committees of the International Commission on Units and Measurements, and the International Commission on Radiological Protection.

Dr Stefan Pelc
FInstP (1908–73) held his first post at the Radium Research Institute at Lainz Hospital near Vienna and joined the Hammersmith Hospital, London in 1943 as Physicist. At the MRC Radiotherapy Research Unit, he invented the 'stripping film autoradiography' technique using it to study iodine-131 uptake in the thyroid. He and Alma Howard, using phosphorus-32, made the famous discovery of the cell cycle, showing that DNA was synthesized at only one particular time during interphase – thus laying the foundation of cellular kinetics.

Sir Eric Pochin
Kt CBE FRCP (1909–90) was a member of the scientific staff of the MRC in 1941 and Director of the Department of Clinical Research, University College Hospital Medical School, London, from 1946 to 1974; a member of the International Commission on Radiological Protection, 1959, Chairman from 1962 to 1969, Emeritus member from 1977; and a member of the National Radiological Protection Board from 1971 to 1982.

Professor John Eric Roberts
HonFIPEM FInstP (1907–98) worked with W V Mayneord from 1932 to 1937 at the Cancer Hospital (Free) in South Kensington, London, investigating the dosimetry of X-rays generated at 400 kV. He then took up a post at the Middlesex Hospital Medical School and succeeded Professor Sidney Russ in 1946 as Joel Professor of Physics Applied to Medicine. During his 25 years there he encouraged the advance of physics in varied aspects of hospital work and stimulated the formation in 1961 of the Institute of Nuclear Medicine. From 1938 onwards he trained many physicists and in 1943, 53 came together to form the HPA. He was President of the HPA (1950–51) and of the BIR (1951–2); and the first Editor of *Physics in Medicine and Biology* from 1956 to 1961. See obituaries: the *Independent* (5 November 1998); the *Gazette* (19 November 1998).

Professor Wilhelm Conrad Röntgen
(1845–1923) received the first Nobel Prize for Physics, in 1901, for his discovery of X-rays. He studied at the Polytechnic in Zürich and was then Professor of Physics at the Universities of Strasbourg (1876–9), Giessen (1879–88), Wurzburg (1888–1900) and Munich (1900–20). See http://nobelprize.org/nobel_prizes/physics/laureates/1901/rontgen-bio.html (visited 20 July 2006).

Professor Sir Joseph Rotblat KCMG CBE FRS HonFInstP HonFRSE HonFRCR HonFMedSci (1908–2005) was Professor of Physics in the University of London, at St Bartholomew's Hospital Medical School, from 1950 to 1976, then Emeritus; Physicist to St Bartholomew's Hospital from 1950 to 1976 and President, Pugwash Conferences on Science and World Affairs (1988–97), then Emeritus. He was President of the HPA from 1969 to 1970, and of the BIR, from 1971 to 1972. He was awarded the Nobel Peace Prize in 1995. See Marshall (1995); Jones (2005). See also http://nobelprize.virtual.museum/nobel_prizes/peace/laureates/1995/rotblat-cv.html (visited 20 July 2006).

Professor Sidney Russ CBE FInstP (1879–1963) was Demonstrator in Physics at the University of Manchester (1906–10), Beait Memorial Fellow at the Cancer Research Laboratories, the Middlesex Hospital (1910–12), Physicist to the Middlesex Hospital, (1913–46), Professor of Physics, Medical School, Middlesex Hospital (1920–46), later Professor Emeritus, and Scientific Secretary of the National Radium Commission (1929–35). In 1943, he convened the meeting which launched the HPA and was elected its first Chairman (1943–4). See Windeyer (1963); Jennings (1998).

Professor Peter Sharp FInstP FIPEM FRSE (b. 1947) took his bachelor's degree in physics at the University of Durham before moving to Aberdeen in 1969 to study for a PhD with Professor John Mallard. He was appointed lecturer in medical physics in 1974 and awarded a personal chair in 1990. On the retirement of Professor Mallard in 1992, he was appointed to the Chair of Medical Physics. He was head of the nuclear medicine physics group at Aberdeen Royal Infirmary and in 1992 was appointed Head of Medical Physics to what is now NHS Grampian and Head of the NHS department of Medical Physics.

Professor Rod Smallwood FREng HonFRCP FIEE FInstP FIPEM (b. 1945) has been Professor of Computational Systems Biology and the Director of Research for Engineering at the University of Sheffield. Following a first degree in Physics from UCL, he studied solid-state physics at Lancaster before joining the NHS in Sheffield. He worked mainly on instrumentation for noninvasive physiological measurement. In 1995 he became Professor of Medical Engineering and Head of the academic Medical Physics and Clinical Engineering Department, and took up a new post in computer science in 2002. His current research is on emergent behaviour resulting from cellular interactions. He is a past-President of the Institute of Physics and Engineering in Medicine.

Dr Gottfried Spiegler
FInstP FRPS (1891–1979) was appointed Physicist to the Central Röntgen Institute in Vienna in 1922, and published extensively on X-ray photography. He joined the Royal Cancer Hospital, London, in 1942 to work with Val Mayneord, retiring in 1958. His studies on secondary emission from metal foils resulted in a design of film badge which gave excellent discrimination between radiations of differing quality. See Haggith (1983): 128.

Professor William (Bill) Spiers
CBE FInstP (1907–93) was appointed Physicist to the General Infirmary at Leeds in 1935 and became the first holder of the Chair of Medical Physics at Leeds University in 1950; Professor of Medical Physics (1950–72), then Emeritus. He was President of the BIR (1955–6), Chairman of the HPA (1944–5), and of the British Committee on Radiation Units and Measurements (1967–77). See Haggith (1983): 129.

Professor Gilbert Stead
FInstP FRSA (1888–1979) was Reader in Physics, Guy's Hospital Medical School, University of London (1923–38), Professor of Physics (1939–53), Honorary Consulting Physicist to Guy's Hospital (1948–53), Professor Emeritus of Physics in the University of London (1953–79) and Consultant Physicist Emeritus to Guy's Hospital (1953–79). He was President of the BIR (1947–8) and of the HPA (1951–2). See Haggith (1983): 130.

Frank Stewart
MIEE (b. 1908) in the 1940s, in Hal Gray's group at Hammersmith, joined in the pioneering clinical applications of radioisotopes with N Veall, E W Emery, S Pelc and others. He was the Honorary Secretary of the HPA Diagrams and Data Scheme for five years. In 1967 he worked closely with the BECC's Research Unit in Radiobiology at Mount Vernon and built a reflectance photometer which measured skin erythema. In 1970 he joined the BECC Unit, then renamed the Gray laboratory, as Head of Physics.

Leo Szilard
(1898–1964), initiated the Manhattan Project for developing an atomic bomb during the Second World War. With Einstein, he in

1939 drafted a letter to President Roosevelt recommending an atomic energy programme. The US atomic energy effort became known as the Manhattan Project in 1942. In 1945, when the atomic bomb was ready, Szilard circulated a petition, signed by a number of his fellow atomic scientists, asking that it not be used against Japan. After the war Szilard involved himself in efforts to control nuclear arms, and abandoned nuclear physics for work in the field of biology. See Lanouette and Silard (1992).

Dr Adrian Thomas
FRCP FRCR (b. 1954) is Consultant Radiologist, The Princess Royal University Hospital; Honorary Librarian and Archivist, the BIR; and Chairman of the British Society for the History of Radiology.

Professor Silvanus Thompson
FRS (1851–1916) was Professor of Physics in the City and Guilds Technical College and Principal of the College at Finsbury, London, and first President of the Illuminating Engineering Society. See Thompson and Thompson (1920).

Dr Peter Tothill
(b. 1922) held medical physics posts successively at Mount Vernon Hospital, London, from 1947 to 1953, St Thomas' Hospital, London, from 1953 to 1955, St William's Hospital Radiotherapy Centre, Rochester, Essex, from 1955 to 1958, and from 1958 until retirement in 1988 (and after) in the Department of Medical Physics in Edinburgh, specializing in nuclear medicine, radiation protection and bone measurement.

Mr Theodore Tulley
FInstP (b. 1918) was assistant physicist at the Royal Cancer Hospital (Free) (1942–8), Physicist at the Hull Royal Infirmary (1948–60), and Deputy Regional Physicist to the Leeds Regional Hospital Board, later Yorkshire Regional Health Authority (Hull) (1960–81). He was Secretary, HPA Northern Group (1957–9), Member of the Executive Committee (1965–7) and member of the Radiation Protection Topic Group (1970–3).

Professor Peter Wells
FRS FREng FMedSci (b. 1936) trained in engineering, physics and zoology. He was a research assistant in the United Bristol Hospitals (1960–71), Professor of Medical Physics in the Welsh National School of Medicine (1972–4), Chief Physicist to the United Bristol Healthcare NHS Trust (1975–2000), Honorary Professor in Clinical Radiology in Bristol University (1986–2000)

and Professor of Physics and Engineering in Medicine in Bristol University (2000–1), now Emeritus. He is now Distinguished Research Professor at Cardiff University and Visiting Professor at Imperial College, London.

Professor John West
FRCP (b. 1928) was at the Royal Postgraduate Medical School, Hammersmith Hospital, London, for 15 years and since 1969 has been Professor of Medicine and Physiology at the University of California, San Diego.

Mr John Wilkinson
FIPEM (b. 1944) worked at the Royal Northern Hospital, London, the Ontario Cancer Institute, Toronto, and the Hôpital Cantonal, Geneva, before joining the radiotherapy physics group at the Christie Hospital, Manchester, in 1972. He became Consultant Physicist in 1990 and leader of the radiotherapy physics group at the Christie Hospital in 1999.

Professor Peter Williams
FIPEM (b. 1949) joined the Christie Hospital, Manchester, in 1969 and trained in radiotherapy physics. He was appointed as Director of North Western Medical Physics, a regional department based at the Christie Hospital, in 1999 and has held an Honorary Chair in radiological physics at the University of Manchester since 2001. He served as President of the Institute of Physics and Engineering in Medicine from 2003 to 2005.

Sir Solly Zuckerman
Kt OM KCB FRCP FRS (1904–93) Baron Zuckerman of Burnham Thorpe, joined the faculty of Oxford University in 1934 and was professor of anatomy at Birmingham University from 1946 to 1968. He did extensive research on primates, publishing a number of books that became classics in their field, including *The Social Life of Monkeys and Apes* (1932) and *Functional Affinities of Man, Monkeys and Apes* (1933). He was chief scientific adviser to the British government from 1964 to 1971. See Krohn (1995).

Glossary*

angiogenesis
The formation of new blood vessels, especially those that supply oxygen and nutrients to cancerous tissue.

atom
The smallest part of an element that has all properties of that element. Its nucleus consists of protons and neutrons, surrounded by orbiting electrons.

audiometer
An electrical instrument for measuring the threshold of hearing for pure tones of normally audible frequencies generally varying from 200 to 8000 hertz and recorded in decibels.

autoradiography
A technique using **X-ray** film to visualize molecules or fragments of molecules that have been radioactively labelled.

biomaterial
Material used to construct artificial organs, rehabilitation devices or prostheses, and to replace natural body tissues.

brachytherapy
A procedure in which radioactive material sealed in needles, seeds, wires or catheters is placed directly into or near a tumour.

curie
A measure of radioactivity. One curie of radioactive material (Ci) will have 37 billion transformations of **atoms** (disintegrations) in one second (1 Ci = 3.7×10^{10} Bq). One curie of radium weighs approximately 1 g.

cyclotron
A device that uses alternating electric fields to accelerate subatomic particles (a particle smaller than an atom, such as an alpha particle or a proton). When these particles strike ordinary nuclei, radioisotopes are formed.

dosemeter
An instrument that measures the dose of **ionizing radiation.**

dosimetry
The measurement and calculation of radiation doses.

electrolyte
A chemical compound that ionizes when dissolved or molten to produce an electrically conductive medium.

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* Terms in bold appear in the Glossary as separate entries

fluoroscopy

An **X-ray** procedure that makes it possible to see internal organs in motion. After the X-rays pass through the patient, instead of using film, they are captured by an image intensifier and converted into light. The light is then captured by a TV camera and displayed on a video monitor.

half-life

The measure of the amount of time it takes for half the radioactive **atoms** in an element to decay. For material with a half-life of one week, half of the original amount of activity will remain after one week; half of that (one-quarter of the original amount) will remain after two weeks and so on.

hyperbaric oxygen

Oxygen at a pressure that is above one atmosphere. Also called 'high-pressure oxygen'.

hypoxia

Insufficient levels of oxygen in blood or tissue.

ignitron

A type of controlled rectifier. It is usually a large steel container with a pool of mercury in the bottom, acting as a cathode. A large graphite block, held above the pool by an insulated electrical connection, serves as the anode. An igniting electrode is pulsed to force conduction through the mercury vapour between the cathode and anode. They have been used as high-current rectifiers in major industrial installations where thousands of amperes of AC current must be converted to DC (for example, aluminium smelters).

ionization

The process by which a neutral **atom** or molecule loses or gains electrons, thereby acquiring a net electrical charge. When charged, it is known as an ion.

ionizing radiation

Radiation that is powerful enough to alter **atoms** by removing one or more electrons, leaving positively charged particles (**ionization**). The most common types are alpha radiation, made up of helium nuclei; beta radiation, made up of electrons; and gamma and X-radiation, consisting of high-energy particles of light (photons).

isotopes

Forms of a chemical element whose nuclei have the same atomic number (protons) but different atomic masses (neutrons). The term is usually used to distinguish nuclear species of the same chemical element (those having the same number of protons, but different numbers of neutrons), such as iodine-127 and iodine-131.

magnetron

Thermionic valve (electron tube) for generating very high-frequency oscillations, used in radar and to produce microwaves as used in a microwave oven. The flow of electrons from the tube's cathode to one or more anodes is controlled by an applied magnetic field.

nuclear magnetic resonance (NMR) imaging (or MRI)

The absorption or emission of electromagnetic energy by nuclei in a static magnetic field, after excitation by a suitable radiofrequency magnetic field. The peak resonance frequency is proportional to the applied magnetic field.

nuclide

An **atom** specified by its mass number, being the total of protons plus neutrons in its nucleus, so iodine-131 has 53 protons and 78 neutrons.

parabolic reflector

A concave reflector used to produce a parallel beam when the source is placed at its focus or to focus an incoming parallel beam.

radiation

Energy in the form of high-speed particles (ionizing) or electromagnetic waves (nonionizing).

radioactivity

The spontaneous emission of radiation from the nucleus of an **atom.**

radiograph

A film with an image of body tissues that is produced when the body is placed adjacent to the film while radiating with **X-rays.**

radioisotope

A radioactive isotope, used in medical research as tracers. See also **isotope, nuclide and radionuclide.**

radionuclide

A radioactive **nuclide.** Often used to distinguish **radioisotopes** of different chemical elements, such as iodine-131 and uranium-239.

radiotherapy

The treatment of disease with **ionizing radiation.** Also called radiation therapy.

radon

A gaseous product of radium, and in equilibrium emits the same gamma-ray spectrum as radium but with a **half-life** of 3.82 days.

scintillation counter

A device for detecting and counting scintillations produced by **ionizing radiation.**

thyrotoxicosis

A condition resulting from excessive concentrations of thyroid hormones in the body, as in hyperthyroidism. One of the symptoms of this condition may be anxiety.

transducer

A device that converts one form of energy into another. For example, a thermistor which converts heat into an electrical voltage, and an electric motor which converts an electrical voltage into mechanical energy.

ultrasound

Sound waves, or mechanical vibrations, beyond the range of human hearing. In the medical context, these are in the region of one to 20 million vibrations per second.

ultraviolet

Ultraviolet light or the ultraviolet part of the spectrum. The range of invisible radiation wavelengths from about 4 nanometers, on the border of the **X-ray** region, to about 380 nanometers, just beyond the violet in the visible spectrum.

units of radiation

The unit of radiation exposure is the röntgen (R). (1 R = 2.58 x 10^{-4} C/Kg) It is a measure of ionization in air, technically equal to one ESU (electrostatic unit) per cubic centimetre, due to radiation. The unit of radiation absorbed by the body is the rad, equal to 100 ergs (energy unit) per gram of exposed tissue. One röntgen corresponds to roughly 0.95 rad. The currently accepted unit of radiation is the gray (Gy), the International System unit of absorbed dose, equal to the energy imparted by ionizing radiation to a mass of matter corresponding to one joule per kilogram.

units of radioactivity

The becquerel (Bq) is a measure of radioactivity equal to one atomic disintegration per second. The **curie** (Ci) is a standard based on the radioactivity of 1 g of radium. It is equal to 3.7 x 10^{10} becquerels.

X-rays

Invisible, highly penetrating electromagnetic radiation of a much shorter wavelength than visible light, was discovered in 1895 by Wilhelm Röntgen. See **ionizing radiation**.

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