Unit 20: Medical Physics Techniques

Unit code: F/502/5564
QCF Level 3: BTEC National
Credit value: 10
Guided learning hours: 60

Aim and purpose

The aim of this unit is to enable learners to develop, through a practical vocational skills approach, an understanding of the important fundamental physics concepts behind medical physics techniques such as x-rays, ultrasounds, diagnostic imaging and magnetic resonance imaging (MRI) and radiotherapy. Learners will also understand the importance of radiation safety.

Unit introduction

Diagnostic medicine has come a long way since the time when the best diagnosis occurred during the post-mortem examination. Surgery today is faster, less invasive and more effective than ever – thanks in part to improvements in medical imaging technology. Imaging gives the doctor a clearer understanding of the patient's condition so treatment can be planned more effectively and therapy delivered more precisely.

Nuclear medicine is providing hope for the cure of the most serious diseases, especially cancer. Radioactive materials are used in this rapidly developing branch of medicine. At the cutting edge of developments in nuclear medicine is the precise targeting needed to get the radiation to the exact site of the cancer.

Future prospects are even more exciting. Medical imaging is extending human vision into the very nature of disease; at the cellular level it will permit diagnosis before symptoms even appear. Surgery in the future will be bloodless, painless and non-invasive. It will be powered by medical imaging systems that focus on the disease and use energy to destroy the target but preserve healthy tissue. Researchers are testing the use of high-intensity ultrasound to destroy tumours identified and targeted while the patient lies in an MRI scanner.

This unit introduces learners to some of the established practices in medical physics imaging. It aims to deliver the underpinning knowledge of several of the fundamental techniques and provide a basic introduction to the more complicated theory of magnetic resonance imaging.

Learning outcomes

On completion of this unit a learner should:

1 Know atomic structure and the physical principles of ionising radiation and ultrasound

2 Understand how radiopharmaceuticals are used in diagnostic imaging

3 Know the basic principles of magnetic resonance imaging

4 Understand the importance of radiation safety to the treatment of malignant disease with radiotherapy.

Unit content

1 Know atomic structure and the physical principles of ionising radiation and ultrasound

Radioactivity: industrial applications; atomic structure; characteristics of alpha, beta (β^+ and β^-) and gamma radiations; random nature of radioactive decay, half-life $t_{\frac{1}{2}}$, decay constant λ and activity $A = A_0 e^{-\lambda t}$, $A = \lambda N$

X-rays: industrial applications eg production of x-rays from a target; x-ray spectrum and effect of tube voltage, tube current, target material and filtration; interaction of x-rays with matter; attenuation, inverse square law, absorption and scattering, intensity $I = I_0 e^{-\mu x}$ and half value thickness $x_{\frac{1}{2}} = \frac{\ln 2}{\mu}$

Ultrasound: industrial applications; production of ultrasound and basic principles of eg pulse echo technique, reflection $\left[\alpha = \frac{(z_2 - z_1)^2}{(z_2 + z_1)^2}\right]$ and refraction, interaction with tissue, scattering and absorption; intensity measurement in decibels; specific acoustic impedance; sonar principle and ultrasonic scanning eg A-scan, B-scan and M-scan; Doppler effect; measurement of blood flow using Doppler ultrasound

2 Understand how radiopharmaceuticals are used in diagnostic imaging

Radionuclides: industrial applications eg radionuclides; radionuclide generators and preparation of radiopharmaceuticals; the need for quality control, sterility and apyrogenicity; advantages and disadvantages of radionuclide imaging

The gamma camera: operating principles of main components; function as a detector

3 Know the basic principles of magnetic resonance imaging

Nuclear magnetic resonance: industrial applications; proton spin, energy levels and precession; resonance; overview of process, eg block diagram; factors influencing signal intensity; relaxation, contrast and resolution

Instrumentation and equipment: magnets, gradient field coils, radio frequency coils

MRI applications and safety: abnormal body water, joints, abdomen, head and spine; instruments and equipment, implants, patient tolerance and quenching

4 Understand the importance of radiation safety to the treatment of malignant disease with radiotherapy

Effect of x-rays: effect on cells and tissue in relation to malignant disease; absorbed and effective doses

Radiotherapy: types eg megavoltage and superficial therapy; beam characteristics, multiple and rotational beams, wedges and compensators; linear accelerator; industrial applications

Radiation safety: major effects of ionising radiation on the body; outline of the need for legislative requirements and dose limits; use of film badges and thermoluminescent dosimeters; procedures for reducing radiation hazards

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe radioactivity, including atomic structure [TW1,5]	**M1** explain the random nature of decay and how it relates to half-life	**D1** analyse the effect of the operation and design of the tube/head on a typical x-ray spectrum
P2 describe the production of x-rays and ultrasound		
P3 describe the production and detection of radiopharmaceuticals [IE1,2; SM3]	**M2** compare the desirable biological properties and radiological properties of radionuclides used for imaging	**D2** evaluate the choice of radiopharmaceuticals for a range of clinical imaging requirements
P4 explain the role of pharmaceuticals within the operating principles of the gamma camera [TW1,5]		
P5 outline the process of magnetic resonance imaging including the instrumentation and equipment used [IE1,2]	**M3** explain the factors influencing signal intensity in MRI	**D3** evaluate the appearance of bone and soft tissue in an MRI scan and a conventional x-ray
P6 explain the principles and effects of radiation therapy including the equipment used [IE1,2; SM3].	**M4** explain how excessive exposure to radiation can cause harm.	**D4** evaluate a range of therapy techniques, types of radiation available and the equipment used.

PLTS: This summary references where applicable, in the square brackets, the elements of the personal, learning and thinking skills applicable in the pass criteria. It identifies opportunities for learners to demonstrate effective application of the referenced elements of the skills.

Key	IE – independent enquirers	RL – reflective learners	SM – self-managers
	CT – creative thinkers	TW – team workers	EP – effective participators

Essential guidance for tutors

Delivery

Each learning outcome has a significant amount of underpinning knowledge and is best delivered by starting with the industrial applications. The practical opportunities are limited in this unit but work should be developed, where possible, to support learning outcome 1. It is unlikely that centres will have the facilities for learners to carry out practical work for the remaining learning outcomes. Therefore, tutors should use video recordings, computer simulations, visits to hospital medical physics departments and guest speakers. Lectures, group work and directed reading would also be appropriate in this unit.

If learners will be working in hospital departments it may be possible for additional practical investigations to be undertaken in the workplace. There is an opportunity in this context to make the methods of assessment more inventive – the more this happens, the greater the potential benefit for learners to get more insight into the wide and expanding range of possible nuclear medicine-based careers available.

If the tutor can convey the necessary enthusiasm for what is a remarkable area of science and actively work to engage learners through different methods of delivery, it should be a rewarding experience for everybody. It is suggested that each area of medical imaging continues to be covered throughout the criteria. For example, nuclear medicine begins with basic principles in learning outcome 1, techniques examined in learning outcomes 2 and 3 and safety addressed in learning outcome 4.

This is a complex subject and care should be taken not to exceed the level of the course, especially with the section on MRI which should only be dealt with qualitatively.

Learners should be made aware that our world is radioactive and has been since it was formed. Every day, we ingest and inhale radionuclides in our air, food and water, but the safety procedures and sterility required when dealing with radionuclides for medical uses should be stressed.

Outline learning plan

The outline learning plan has been included in this unit as guidance and can be used in conjunction with the programme of suggested assignments.

The outline learning plan demonstrates one way in planning the delivery and assessment of this unit.

Topic and suggested assignments/activities and/assessment
Introduction to unit content and programme outline. Theory input: nature, properties and industrial applications of radioactivity. Practical activities: practical investigations of properties of alpha, beta and gamma sources including absorption by materials and by air, inverse square law and half-life. Learner activity: use CD ROM or internet to identify how the basic properties of alpha, beta and gamma radiation are applied in medical physics contexts. Theory input: production, nature, properties and industrial applications of x-rays. Learner home-study task: research medical applications of x-rays (including possible hospital visit). Theory input: production, nature, properties and industrial applications of ultrasound. Learner home study task: Research medical applications of Ultrasound (including possible hospital visit). **Assignment 1: Practical Investigations of Radioactivity (P1, P2, M1, D1)**
Theory input: the use, production and detection of radiopharmaceuticals for diagnostic imaging. Learner activity: use CD ROM or internet to identify how the basic properties of radiopharmaceuticals are applied in medical physics contexts. Learner home-study task: research operating principles of a gamma camera. **Assignment 2: Raising Awareness of the Uses of Radiopharmaceuticals With a Gamma Camera in Medical Diagnosis (P3, P4, M2, D2)**
Theory input: basic principles of MRI scanning. Learner activity: use CD ROM or internet to find out how an MRI scanner works. Learner home study task: compare and contrast MRI scanning with x-ray imaging. **Assignment 3: An Introduction to How an MRI Scanner Works (P5, M3, D3)**
Theory input: the importance of radiation safety to the treatment of malignant disease with radiotherapy. Learner activity: use CD ROM or internet to understand the effects of ionising radiation on the body and to identify how the safety issues are applied in medical physics contexts. Learner home-study task: research radiotherapy – recent developments in targeted radiotherapy. **Assignment 4: Risks and Benefits of Using Radiation With Patients (P6, M4, D4)**
Review of unit and programme of assignments.

Assessment

All the pass grade criteria must be met in order for a learner to achieve this unit.

The assessment of P1, M1 and D1 could be aided by learners having practical experience of radioactive sources. As the cost of keeping these sources and the safety issues concerned can be prohibitive, tutors should make use of one of the excellent virtual experiments available on the web or on CD ROM. In addition for D1, learners must explain the types of spectrum before the effects of voltage, current, target material and filters are examined.

For P2, learners could produce a poster or similar graphic assignment. For M2 and D2, learners must carry out some background research on the subject of radiopharmaceuticals and summarise the information. The criteria are structured for independent learning and M2 and D2 are clearly differentiated tasks.

For P3, learners must outline the process of MRI and have an understanding of the equipment used. They could produce two simple block diagrams of the process and equipment in a PowerPoint presentation. For M3, learners must explain the factors influencing signal intensity in MRI. They could do this by writing a brief report. For D3, learners must compare the appearance of bone and soft tissue in an MRI scan with that produced by x-ray.

For P4 and D4, learners could write a report on radiotherapy. For M4, learners must explain how excessive exposure to radiation can cause harm. They could do this by making a safety leaflet.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Practical Investigations of Radioactivity	Your laboratory is commissioned to carry out some practical investigations of radioactivity.	Written laboratory reports on practical investigations carried out in a laboratory (or virtually).
P3, P4, M2, D2	Raising Awareness of the Uses of Radiopharmaceuticals With a Gamma Camera in Medical Diagnosis	You have been asked to present a summary of exciting developments in nuclear medicine.	A poster (or other visual display) summarising information and background research on radiopharmaceuticals.
P5, M3, D3	An Introduction to How an MRI Scanner Works	You are explaining to others working in a hospital why MRI scanners are replacing x-ray machines. You need to outline simply how MRI scanning works.	Presentation or written report/simple guide book on how an MRI scanner works, including block diagrams of the process and equipment involved.
P6, M4, D4	Risks and Benefits of Using Radiation With Patients.	You are asked to explain the benefits and risks attached to the various uses of radiation in a hospital.	A radiation safety leaflet based upon risk assessments carried out.

Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

This unit forms part of the BTEC Applied Science sector suite. This unit has particular links with the units shown below in the BTEC National in Applied Science suite of qualifications:

Level 3
Fundamentals of Science
Electrical Circuits and their Applications
Electronics for Science Technicians
Medical Instrumentation

Essential resources

Learners will need access to appropriate laboratory facilities and ICT resources. Library access to a range of physics books at Level 3 standard is also required.

Employer engagement and vocational contexts

Visits to local hospitals and other medical/healthcare facilities and visits from their employees would be valuable in delivering this unit. The use of vocational contexts is essential for delivery and assessment. Centres should aim to develop links with local hospitals and other medical/healthcare facilities where it is possible to observe applications in practice of some or all of radioactivity, x-rays, ultrasound, radiopharmaceuticals, gamma cameras and MRI scanning.

Indicative reading for learners

Textbooks

Breithaupt J – *New Understanding Physics for Advanced Level: Core Book And Course Study Guide (New Understanding Physics)* (Nelson Thornes Ltd, 2000) ISBN 9780748743162

Duncan T – *Advanced Physics, 5th Edition* (Hodder Murray, 2000) ISBN 9780719576690

Ellse M and Honeywill C – *Mechanics and Radioactivity* (Nelson Thornes, 2003) ISBN 9780748776603

DVD

Radiation and Health – Energy Foresight support for the science curriculum

Websites

www.goingfora.com/radiology/index.html	The Royal College of Radiologists
www.health.howstuffworks.com/x-ray2.htm	How X-rays work
www.tre.ngfl.gov.uk	Teacher Resource Exchange
www.uhrad.com/ctarc.htm	Body Imaging Teaching Files

Delivery of personal, learning and thinking skills

The table below identifies the opportunities for personal, learning and thinking skills (PLTS) that have been included within the pass assessment criteria of this unit.

Skill	When learners are ...
Independent enquirers	[IE1,2] engaging in research and information gathering into radiopharmaceuticals, MRI scanning and data collection from practical investigations of radioactivity
Team workers	[TW1,5] collaborating with others to plan a visit to a hospital or other medical/ healthcare facility when carrying out research and taking responsibility for their role
Self-managers	[SM3] organising time and resources and planning action to produce a poster on radiopharmaceuticals and a safety leaflet on risks and benefits of uses of radiation in medicine

Although PLTS are identified within this unit as an inherent part of the assessment criteria, there are further opportunities to develop a range of PLTS through various approaches to teaching and learning.

Skill	When learners are ...
Independent enquirers	[IE2,4] planning and carrying out research into locations or sites they plan to visit, plus their own research into the medical physics techniques used and the safety procedures required when they are in use
Creative thinkers	[CT3,5,6] trying different ways to tackle a problem; working with others to find imaginative solutions and outcomes that are of value
Reflective learners	[RL2,4] setting goals and targets within the planning of their work; inviting feedback from others in the group on their poster and safety leaflet

Functional Skills – Level 2

Skill	When learners are ...
ICT – Find and select information	
Select and use a variety of sources of information independently for a complex task	researching exploration, extraction and processing of resources
Access, search for, select and use ICT-based information and evaluate its fitness for purpose	planning for visits or planning a presentation
ICT – Develop, present and communicate information	
Enter, develop and format information independently to suit its meaning and purpose including: • text and tables • images • numbers • records.	producing tables, graphs and maps as part of the report write-up stage following visits; incorporating photographs
Bring together information to suit content and purpose	bringing together information for assignments reports
Present information in ways that are fit for purpose and audience	producing radioactivity investigation and MRI scanner reports producing poster and safety leaflet
Mathematics	
Identify the situation or problem and the mathematical methods needed to tackle it	applying appropriate mathematical methods to solve radioactive decay, x-ray attenuation and acoustic impedance problems
Use appropriate checking procedures and evaluate their effectiveness at each stage	carrying out calculations accurately
Draw conclusions and provide mathematical justifications	evaluating solutions to problems solved through use of mathematical methods
English	
Speaking and listening – make a range of contributions to discussions and make effective presentations in a wide range of contexts	discussing hospital visits and laboratory work risk assessments; presenting the result of research into chosen areas
Reading – compare, select, read and understand texts and use them to gather information, ideas, arguments and opinions	researching background information for hospital visits researching chosen industrial applications from a wide range of sources
Writing – write documents, including extended writing pieces, communicating information, ideas and opinions, effectively and persuasively	writing visit reports.