Radiography: Fundamentals of X-Radiation, Radiation Dosage in Dental Imaging, and Potential Risks of Exposure

Aims: To provide an overview on the basic concepts of X-radiation, radiation dose limits and potential risk of exposure to X-radiation.

Objectives: On completion of this verifiable CPD article the participant will be able to demonstrate, through completion of a questionnaire, the ability to:

- Know the basic concepts of X-radiation
- Be able to describe the history of medical and dental radiography
- Identify dose quantities and units practical to radiation protection in dentistry
- Identify the threshold dose on whole body exposure and localised exposure to x-radiation
- Identify the principles of dose limitation
- Know the difference between classified and non-classified workers

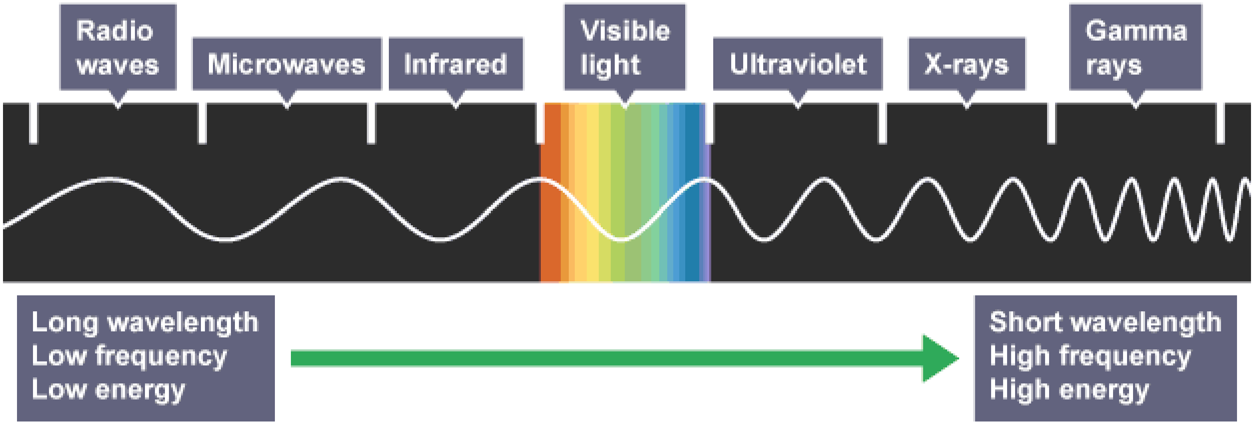
Introduction

Radiography today is an invaluable tool for the dental professional, providing information that is impossible to obtain by clinical examination alone. Techniques exist for imaging the teeth, mandible, maxilla, temporomandibular joints and the oral and labial soft tissues.[1]

In the UK, more dental radiographs are taken than any other radiographic diagnostic image.[2] Some form of radiographic examination is necessary on the majority of our patients and as a result of this, radiographs are often referred to as the clinician's main diagnostic aid.

This article will discuss the basic principles of radiation physics, the risks of ionising radiation and radiation doses in dental radiography.

The Electromagnetic Spectrum



The electromagnetic spectrum is continuous range of wavelengths. The types of radiation that occur in different parts of the spectrum have different uses and dangers- depending on their wavelength and frequency. Each type of radiation has different properties and applications. For example, radio waves are used in communication, microwaves in cooking and communication, visible light allows us to see, and X-rays are used in medical imaging. Gamma rays have the shortest wavelength and highest frequency, while radio waves have the longest wavelength and lowest frequency.

Effects of Electromagnetic Radiation

Electromagnetic radiation can have various effects depending on its intensity, wavelength, and exposure duration.

1**. Ionising Radiation Effects**: High energy electromagnetic radiation, such as x-rays and gamma rays, is ionising radiation. It has enough energy to remove electrons from atoms, leading to the formation of charged particles called ions. Ionising radiation can damage DNA and cells, increasing the risk of cancer and genetic mutations. Ionising radiations is used in medical imaging (including dental x-rays), and cancer treatment but must be carefully controlled to minimise health risks.

2. **Non-Ionising Radiation Effects:** Lower energy electromagnetic radiation, such as visible light, infrared radiation, microwaves, and radio waves, is non-ionising radiation. Non ionising radiation typically lacks the energy to ionise atoms but can still cause biological effects. For example:

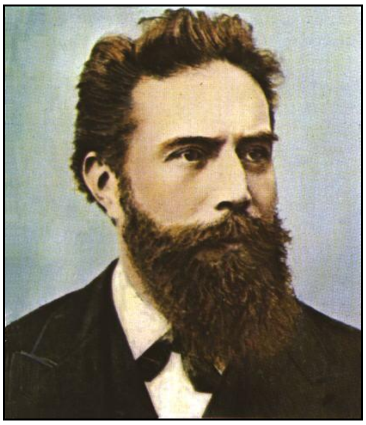
- **Thermal Effects**: Microwave and infrared radiation can generate heat in tissues, potentially causing burns or tissue damage with prolonged exposure.

- **Photochemical Effects**: Ultraviolet (UV) radiation from the sun can cause sunburn, aging, and increase the risk of skin cancer through indirect DNA damage.

- **Electromagnetic Interference**: Radiofrequency radiation, including those from electronic devices like mobile phones, can interfere with sensitive equipment and disrupt communication systems.

Overall, the effects of electromagnetic radiation range from the beneficial (such as in dental imaging) to potentially harmful (such as in excessive exposure to ionising radiation or UV radiation). Regulatory guidelines and safety measures are in place to mitigate risks and ensure that electromagnetic radiation exposure remains within safe limits.

The History of Radiographs



Wilhelm Conrad Röntgen

Wilhelm Conrad Röntgen discovered X-rays in November 1895. There are many different accounts as to how this discovery occurred. One such account is that Röntgen was experimenting with cathode rays (electrons) in a high energy cathode ray tube. Röntgen observed that there was a plate of barium platinocyanide nearby, which glowed in the dark. Röntgen dubbed these mysterious rays capable of passing through glass "X" (for unknown) and subsequently tried to block them with a variety of material. He used aluminium, copper and even the walls of his laboratory to no avail.

When Röntgen held a piece of lead in front of the electron-discharge tube, it blocked the rays, but he was able to see his own flesh glowing around his bones on the fluorescent screen behind his hand.[3] The image below, said to be of Röntgen's wife's hand, is thought to be the first documented radiograph on a human body.


The first medical radiograph

In 1901 Wilhelm Konrad Röntgen was the first recipient of the Nobel Prize for Physics. His discovery revolutionised the medical world, making it possible to look inside the human body without surgical intervention. Within a year, the first radiology department opened in a Glasgow hospital, and the department head produced the first pictures of a kidney stone and a penny lodged in a child's throat. Shortly after, an American physiologist used X-rays to trace food making its way through the digestive system.

In 1896, Dr Otto Walkhoff was credited with the first dental radiograph which was in his own mouth and was taken on glass plates wrapped in rubber dam.


Dr Otto Walkhoff

The image below is of an early x-ray machine. Although the basic design of the X-ray machine has not changed much, the required exposure time has. An exposure today can be measured in milliseconds, whereas the exposure time for the first dental radiograph was 25 minutes.[4]

1920s X-ray machine

Modern X-Ray Machine

As previously discussed, X-rays are a type of electromagnetic radiation generated through a process called x-radiation, typically achieved by accelerating electrons to high speeds and directing them to collide with a magnetic target, such as tungsten. When electrons strike the target, about 1% of their energy is given off as X-radiation and the remaining 99% is given off as heat.

An x-ray tube head is a glass tube with a cathode (negative terminal) and an anode (positive terminal). This is sealed in oil and steel and then shielded in lead to control stray x-rays. X-rays only pass through a thin window down the tube head. The x-rays are only emitted when the exposure button is pressed, which then pass through teeth and surrounding tissues. The sensor or film which is placed in the mouth captures the x-rays that were not absorbed by the body's tissues.

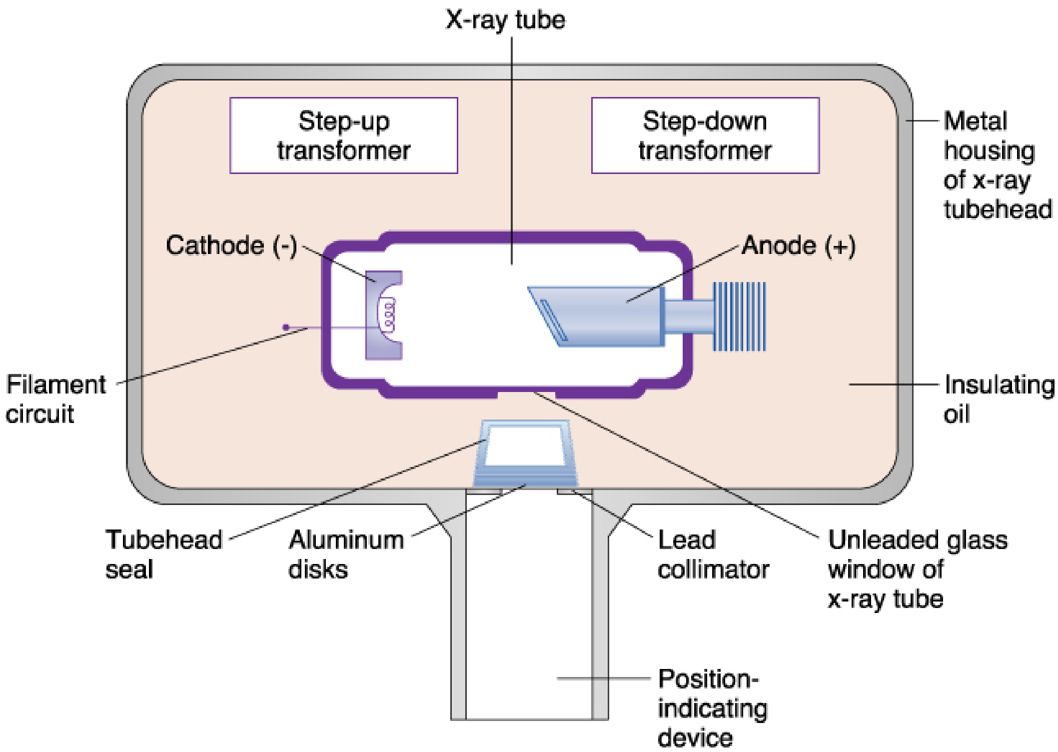
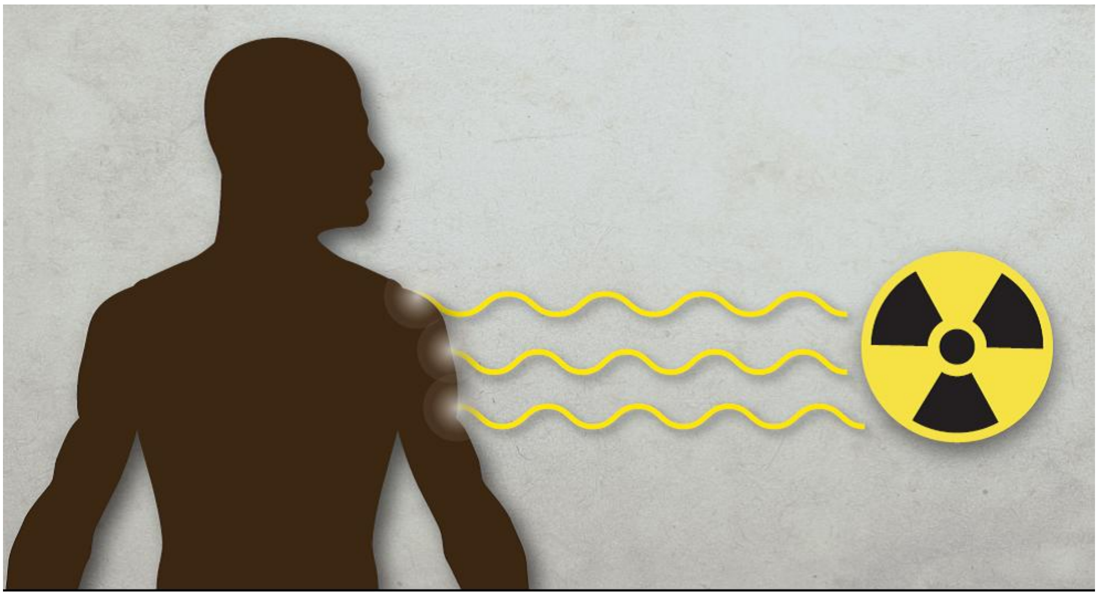


Diagram of x-ray tube head [5]

There are four principal types of x-ray sets as follows[6]:

Equipment	Use	Typical kV/mA
Intra-oral X-ray set	Radiograph of small section of the jaws and teeth.	60-70kV 7-10mA
Panoramic X-ray set	Radiograph of whole of both jaws or sections.	60-90kV 1-15mA
Cephalometric X-ray set	Radiograph providing detailed image of the whole skull	60-90 kV 1-15 mA
Cone Beam Computed Tomography (CBCT)	Three dimensional or sectional views of parts of jaws/teeth, or regions of skull, using software	60-125 kV 1-15 mA

Radiation Dose



There are three common terms used to describe radiation dose:

1. **Absorbed dose** – This refers to the amount of energy absorbed per unit mass by a material or tissue. It is typically measured in gray (Gy), where 1 gray equals 1 joule of radiation energy absorbed per kilogram of mass.

2. **Equivalent dose** – This measures the biological effect of radiation on living tissue, considering the type of radiation and its potential to cause damage. It is calculated by multiplying the absorbed dose by a radiation weighting factor, which reflects the varying biological effects of different types of radiation. Equivalent dose is measured in sieverts (Sv). Since the radiation weighting factor for X-radiation is 1, the absorbed dose and equivalent dose are numerically identical in dental radiography.

3. **Effective dose** – This provides a more comprehensive estimate of overall radiation risk by accounting for the type of radiation, the dose received, and the sensitivity of different organs and tissues. Some organs are more susceptible to radiation than others, so effective dose applies tissue weighting factors to reflect these differences. It is also measured in sieverts (Sv).

Effective dose and equivalent dose are often referred to simply as "dose," but the context typically clarifies whether the exposure applies to the whole body or a specific organ.

A dose of **1 SV** is a very large dose and enough to cause radiation injuries. However, during routine dental radiography, doses to employees and patients are measured in thousandths and millionths of a Sievert.[7] The table below denotes the fractions of a Sievert that are used to measure doses in radiography.

Fraction	Prefix	Abbreviation
1/1000th	Milli	m
1/1000 000th	Micro	u
1/1000 000 000	Nano	n

When comparing radiation dosage, it is important to be aware that every day, we are exposed to natural background radiation. The table below shows typical doses from some of the main dental radiographic examinations and highlights the comparison with some natural sources of radiation that an individual receives each year from background radiation or occupational exposure.[6]

Type of radiographic examination	Effective dose (whole body) mSv
Intra Oral (Bitewing/periapical)	0.0003-0.022
Panoramic	0.0027-0.038
Lateral cephalometric	0.0022-0.0056
Cone beam computed tomography	0.01-0.67
Circumstance	**Approximate Effective dose (whole body)**
UK background radiation	2.3 mSV/year
Background (world max)	50 + mSV/year
Average occupational dose (UK)	<1 mSv/year
Annual effective dose limit (employees)	20 mSv/year

The dose received depends on several factors such as the sensitivity of the image receptor (the higher the speed, the lower the dose required), the area exposed to the primary beam and the exposure factors selected.[6]

Health Risks

Dr George Pirie was a pioneer in the clinical application of medical radiographs, but he was forced to retire due to ill health. After 10 years of nearly daily exposure to primitive x-rays his eyesight began to fail, and he developed characteristic tumours in his hands. He lost his right hand and the thumb and part of his little finger on his left hand which eventually was also amputated. Once the danger of exposure to X-rays was realised, early forms of protection included a lead-lined mask with glass goggles. Fortunately, the dose from X-radiation exposure today is much lower than it used to be.

As far as the risks to health are concerned, the probability of developing cancer from ionising radiation is derived from studies of populations that have received known and usually significant radiation doses. These include:

- The survivors of the nuclear disaster at Chernobyl
- Radiation workers
- Person's exposed during certain medical procedures[6,7]

The radiation exposures for these populations have been relatively high, with doses received mainly from acute exposures. Thus, knowledge of the risk of these high levels does exist, but our knowledge of the risks at low exposure is more limited.
However, it is estimated to follow a roughly linear line (figure 1) and no dosage of radiation, no matter how small, is without risk. This is called the 'no threshold theory'.[7]

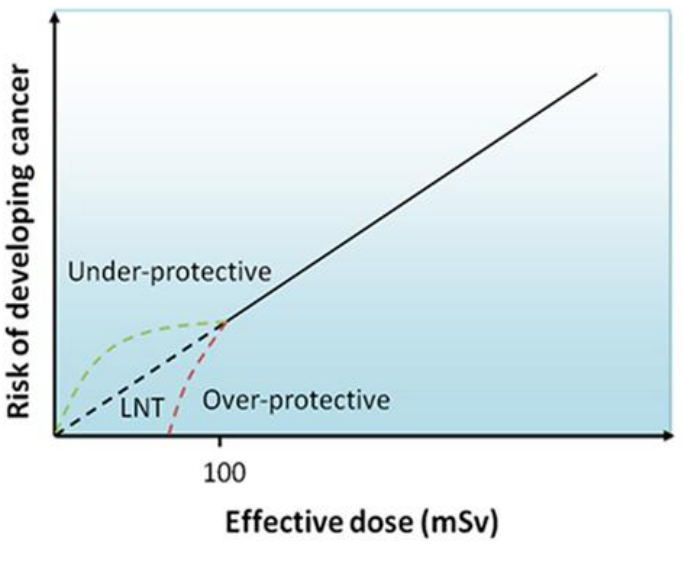


Figure 1 The Risk of Developing Cancer from Ionising Radiation

The risks of cancer induction depends on many factors which include the type of radiation, the organs of the body that are irradiated and the age at exposure. Individuals that have higher risk factors of contracting cancer such as smokers, are also thought to have a higher risk of cancer induction following radiation exposure. The following table from public Health England, shows the risk of fatal cancer associated with radiation exposure, in perspective:

Scenario	Estimated Risk of fatal cancer
UK average	1 in 3
Smoking 20 cigarettes per day	1 in 100
Single exposure of 100 mSv	1 in 2500
Single exposure of mSv	1 in 25000
Teeth (single bitewing) x-ray	Less than 1 in 1,000,000

The table below shows the effect of ionising radiation and corresponding threshold dose. However, the values apply only in respect of acute doses when the dose is received in a single exposure, or over a short period of time. Where the dose is received over a longer period of time the effects may be very much less pronounced.[6]

Effect	Approximate Threshold Dose
Whole Body Exposure	
Detectable chromosome changes	➢ 0.1 SV
Detectable changes in blood count	➢ 1 SV
Radiation sickness	➢ 1 SV
Death possible	➢ 3 SV
Death certain	➢ 10 SV
Localised Exposure	
Erythema (radiation burn)	➢ 5 SV
Depilation (hair loss)	
-temporary	➢ 4 SV
-permanent	➢ 7 SV
Desquamation (skin loss)	➢ 20 SV

Dose Limitation

We can say that dental x-ray examinations involve very low amounts of radiation. To put it in perspective, bitewing radiographs are equivalent to a few days of natural background radiation or a return flight to Spain. However, Public Health England state that, “taking into consideration the assumed ‘linear, no threshold’ relationship between dose and risk, health, and safety law in the UK and elsewhere, requires employers to ensure that the exposure of employees and others is restricted so far as is reasonably practicable.” This is known as the ALARP principle:

As

Low

As

Reasonably

Practicable

The system of dose limitation for work related exposure is based on the principles of:

Justification of practice - The benefit of the exposure to ionising radiation should outweigh the risk.

Optimisation of radiation protection - The exposure should provide the best image quality with the lowest possible dose.

Dose limits for individuals at work and for members of the public - Making sure that the annual doses of ionising radiation received by both staff and patients are limited.

The justification for the frequency that radiographs are taken must be clearly marked in the patient's notes and the risks and benefits should be clearly explained to the patient.

The Guidance Notes for Dental Practitioners contains information on leaflets and a poster that can be downloaded to be displayed and handed to patients.[2] (The poster produced by the Clinical Imaging Board is pictured below). If this method is used it is important that the operator confirms and documents that the patient has read the required information and that they answer any questions the patient has.

Dose Monitoring

When work is carried out in a controlled area under written arrangements, the employer must demonstrate that doses are being restricted. Individual annual doses can be measured, estimated, or calculated and compared to the dose investigation level which is set by the employer. This can be done using one of the following methods which are outlined in the 2020 Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment:

- Issuing all staff who enter controlled areas with a personal dosemeter provided by an approved dosimetry service (ADS) which reports the assessed doses to the employer.

- Issuing staff with direct-reading electronic personal dosemeters that are suitable for use with X-rays and keeping a log of the doses locally.

- Estimating the annual doses based on measurements made at the operator's position as part of the arrangements for area monitoring.[2]

Individuals who work with ionising radiation are divided into two subgroups depending on the level of occupational exposure. These are:

1) Classified workers

These are individuals who receive high levels of exposure to radiation at work. This will be any employees who are likely to receive an effective dose greater than 6 mSv in a calendar year or an equivalent dose to the lens of the eye greater than 15 mSv per year, or greater than 150 mSv per year to the skin or extremities. An upper annual effective dose limit of **20mSv** is set for classified workers.[6] These individuals require compulsory personal monitoring and annual health checks. If local rules are observed this is highly unlikely in dental practice.

2) Non classified workers

These individuals receive low levels of exposure to radiation at work. If local rules are observed, all dental staff should receive an annual effective dose of considerably less than the non-classified limit of **6mSv**.[6]

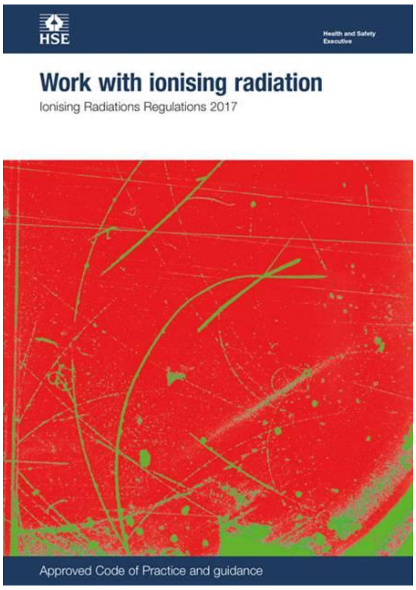
IRR17 states that the **dose investigation level** must not exceed 15 mSv and where appropriate should be set at a lower level, For this reason, the latest 2020 Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment, states that "Doses to employees arising from routine dental radiography that is conducted in X-ray rooms designed and laid out in accordance with this guidance, and following the working procedures set out in this guidance, should be well below 1 mSv" The guidance notes advise that **1mSv** is an appropriate value for the dose investigation level but that whatever level is chosen, it should be documented in the risk assessment and in the local rules.[2]

Reducing the Dose

There are some simple methods that can be employed to reduce the dose of ionising radiation when taking dental radiographs.

- ✓ Justifying every exposure
- ✓ Digital x-rays dramatically reduce the dose
- ✓ A faster film can be used (if wet processing). Using an E speed film can reduce the amount of ionising radiation by 50% and using an F speed film gives an addition 20% benefit
- ✓ A rectangular collimator offers a 40%-50% reduction
- ✓ Film holders and beam aiming devices can reduce the dose by reducing the number of retakes that may be required
- ✓ Ensuring that there is quality assurance system and audits in place to reduce the number of retakes required

Radiation Protection



There are two sets of regulations in the UK governing the use of ionising radiation. These are:

- The Ionising Radiation Regulations 2017 which are which primarily concerned with the radiographic equipment, the workers and the public and are enforced by the Health and Safety Executive.[8]

- The Ionising Radiation (Medical Exposure) Regulations 2017, which are primarily concerned with the protection of the patient. These are enforced in the UK by: the Care Quality Commission (CQC) in England; the Healthcare Inspectorate Wales (HIW) in Wales; the Scottish Executive (SE) in Scotland; and the Regulation and Quality Improvement Authority (RQIA) in Northern Ireland.

These both form part of the Health and Safety at Work Act 1974. The regulations in Northern Ireland are IRR(NI)2017 and IRMER(NI)2018.

These will be discussed in the CPD article titled "Radiography: IRMER and IRR-Radiation Protection and Statutory Requirements in Dental Radiography" and is available on the website. Radiography risk assessment and quality assurance is also available.

Information, Instruction and Training

Employees who operate dental x-ray equipment

Employers must ensure that all of their staff who are trained and qualified to undertake X-ray exposures receive training that includes the following:

- Risks to health arising from exposure to dental X-rays.
- The significant findings of the risk assessment and precautions that need to be taken, in particular the specific requirements of the local rules and contingency plans at their place of work.
- The requirements of IRR17 relevant to dental radiography and the importance of complying with them.

IRMER Practitioners, referrers or operators that take radiographs, need to ensure that they complete IRMER training that meets their needs. The training that you complete depends on your needs at the time of completing it.

The recommended radiation content of verifiable CPD courses for IRMER practitioners and operators who undertake radiography are also set out in the 2020 Guidance notes as follows:

- The principles of radiation physics.
- Risks of ionising radiation.
- Radiation doses in dental radiography.
- Factors affecting doses in dental radiography.
- The principles of radiation protection.
- Statutory requirements.
- Selection criteria (IRMER Practitioners).
- Quality assurance.

You should source training in any new equipment or techniques that you introduce to your daily practice. All additional training that you complete should be logged and recorded.

Staff not directly involved with radiography

Staff that assist in other duties related to radiography such as processing films or phosphor plates, or non-clinical staff, should carry out training sufficient to their role and safety. This may include:

- Awareness that X-rays are used, the benefits and risks, and the need to avoid any personal exposure
- Training in the requirements of the local rules

The General Dental Council highly recommend that dental professionals carry out 5 hours of verifiable CPD on the subject of radiography.

Personal Development Plan and Reflective Learning

This CPD is linked to the following GDC Enhanced CPD Development Outcome:

C. Maintenance and development of knowledge and skill within your field of practice.

Reflective learning is now a requirement of the GDC Enhanced Professional Development Scheme. As such, you will now be given the opportunity to answer some reflective learning questions, before your certificate is generated. This can be updated at any time but, if you take a few moments to write your reflection on completion, you will have fulfilled the Enhanced CPD requirements.

Further Reading

IRR(17)
IRR (17) Northern Ireland
IR(ME)R17
IR(ME)R18 NORTHERN IRELAND
Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment 2nd Edition

References

1. Grange, S. (2009) “Vital Guide to Radiography and Radiation Protection”, Vital (7), PP. 43-46
2. Public Health England (2020) Guidance Notes for Dental Practitioners on the Safe Use of X-ray Equipment 2nd Edition. Available at: https://www.rqia.org.uk/RQIA/files/44/449bdd1c-ccb0-4322-b0df-616a0de88fe4.pdf (accessed 07/02/2025)
3. Waters, H. (2011) The First X-Ray 1895. The Scientist. Available at: . (07/02/2025)
4. RDH Magazine (2015) Dental radiography. Available at: http://www.rdhmag.com/articles/print/volume-31/issue-1/features/dental-radiography.html (accessed 07/02/2025)
5. Haring J, Jansen L: *Dental radiography: principles and techniques*, ed 2, Philadelphia, 2000, Saunders

6. Public Health England (2020) Radiation Safety Refresher for Dental Engineers. Radiation Protection. Leeds

7. Whaites. E (2010) Essentials of Dental Radiography and Radiology. 4 Edn. Elsevier:London.

8. Ionising Radiation Regulations (2017) Available at: http://www.legislation.gov.uk/uksi/2017/1075/pdfs/uksi_20171075_en.pdf (accessed 07/02/2025)

9. Ionising Radiation (Medical Exposure) Regulations. Available at: http://www.legislation.gov.uk/uksi/2017/1322/contents/made (accessed 07/02/2025)