Researchers in Schools

Using X-ray vision to detect threats and contraband

Key Stage 4 Programme

Pupil Name

Coursebook Designed by Dr Alex Shevchuk

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Uni Pathways launch event

Welcome to Uni Pathways! We are delighted to be able to launch the Uni Pathways programme with you. We hope that you are ready to embark on your Uni Pathways journey and that you enjoy the video.
You will be asked to pause the video at times to complete some work in this workbook, so make sure you have a pen / pencil to hand when you start the video.

By the end of the video, you will have

- Learnt about what studying at university means
- Learnt about some of the skills that you will develop during Uni Pathways
- Heard from pupils who have participated in Uni Pathways or The Scholars Programme (which is the same programme!)
- Heard from current university students talking about what life is like at university

If you are in school your teacher will play the video. If you are at home and logged in to a session with your teacher, your teacher will play the video and show it to you. If you are participating independently your teacher will email you the link to the video or the video file. There are opportunities for you to answer some questions, and you will be told when to pause the video to answer them.

Introduction to Uni Pathways

1. Write down what you think a supra-activity is
_____
_____
_____
_____

2. Independent learning is
_____
_____
_____
_____

3. Write down in your own words what resilience means, and come up with a different example to the one mentioned in the PowerPoint.
_____
_____
_____
_____
_____

4. Why do you think analysis and evaluation skills are useful in your academic career?
_____
_____
_____
_____
_____
_____

5. Why do you think analysis and evaluation skills are useful in life in general?
_____
_____
_____
_____
_____
_____

6. What are the different types of learning that university students do?

_____
_____
_____
_____
_____

Pupils' experience of Uni Pathways

You will now watch some pupils talk about their experience of learning a PhD topic and producing a final assignment. Some may refer to The Scholars Programme rather than Uni Pathways. As you heard in the introduction PowerPoint, The Scholars Programme is a very similar programme to Uni Pathways. Listen carefully and then respond to the questions below. Be prepared to share some of your responses with your peers.

1. How did the pupils describe talking about writing a long essay for their final assignment?

_____
_____
_____
_____
_____

2. Write down something that one of the pupils mentioned was particularly interesting in their course.

_____
_____
_____
_____

3. What were some challenges that the pupils met?

_____
_____
_____
_____
_____

Virtual campus tours

You will now go on a virtual tour of some universities! Once you have seen some of the university campuses, respond to the questions below.
Note down something that you liked out of any of the campus tours you saw. It may be a particular building, space, city etc.

_____
_____
_____
_____
_____
_____

1. Were there any similarities between the different university campuses? If so, what are the similarities?

_____
_____
_____
_____
_____

2. If you had to pick one of those universities to go and visit in person, which one would it be and why?

_____
_____
_____
_____
_____

3. Note down some of the societies that you could join at different universities

_____
_____
_____
_____
_____

Meet university students!

You are about to virtually meet or hear from some current university students.
If you are virtually meeting them, think about what questions you would like to ask the students, share your questions with a partner and note those questions down in the space below.

If you are not meeting them but watching some videos that they have made, use the space below to note down what else you would like to find out about university. You can then ask your teacher during Uni Pathways tutorials!

_____
_____
_____
_____
_____
_____
_____
_____
_____

Reflection

Congratulations on completing the launch of the Uni Pathways programme. Before you go, take some time to reflect on what you have learnt by answering the following questions:

1. Are there any aspects of university style learning that you would look forward to? If so, what are they?

_____
_____
_____
_____
_____
_____

2. What challenges do you think students face when learning at university? How would you try to overcome these challenges?

_____
_____
_____
_____
_____
_____

3. What skills do you hope to develop during your Uni Pathways course?

_____
_____
_____
_____
_____
_____

4. What part of Uni Pathways seems the most challenging for you?

_____
_____
_____
_____
_____
_____

5. What are you most looking forward to about Uni Pathways?

_____
_____
_____
_____
_____

Timetable and Assignment Submission

Timetable – Tutorials

Tutorial	Date	Time	Location
1			**UTC Swindon**
2			**UTC Swindon**
3			**UTC Swindon**
4			**UTC Swindon**
5			**UTC Swindon**
6 (Feedback)			**UTC Swindon**
7 (Feedback)			**UTC Swindon**

Timetable – Homework Assignments

Homework Assignment	Description	Due Date
Tutorial 1	Introduction to X-rays	16/03/2021
Tutorial 2	Are X-rays and Visible light the same thing?	23/03/2021
Tutorial 3	Are X-rays the answer to Airport security?	19/04/2021
Tutorial 4	DEXI vs, CT	26/04/2021
Tutorial 5	Final Assignment	21/05/2020

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after midnight on 9th August	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

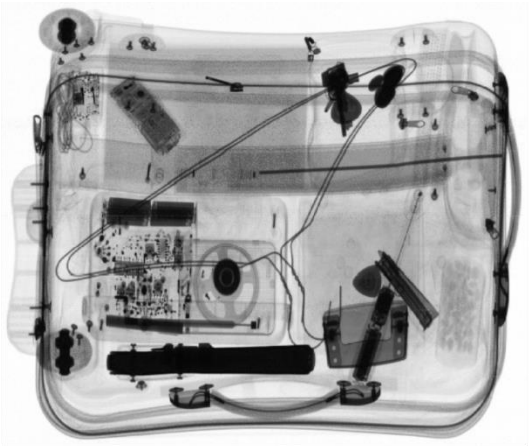
Course Rationale

X-ray technologies are often used in the aviation security industry to inspect passengers, luggage and cargo for the presence of concealed weapons and illicit substances. Over the years, airline bombings, as well as the 2001 September 11th attack on the United States of America, highlighted the importance of an adequate airport security screening system, capable of identifying and preventing explosives and other prohibited items (e.g. knives, guns) from getting on board an aircraft.

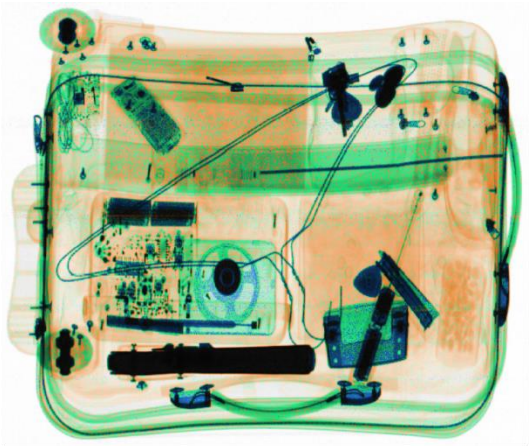
We will study the concept of X-ray imaging, related theory, including how X-rays work and why do we get an X-ray image that we are all used to seeing. We will then look at how scientific theory can be applied to help solve real-world problems and challenges (e.g. distinguish between cheese and explosives), including those outside of its intended use.

We will also look at some of the challenges and concerns related to using X-ray based systems, why X-rays are useful and how they can be used to find hidden and concealed items.

Looking at the two images below: can you identify a threat item? Which image (a or b) makes it easier and why? What do you think the colours mean?



(a)



(b)

This course will be taught in a style of university tutorials, with the final assignment being similar to the work that you would be expected to complete when at University. As part of this course, you will learn how to plan (including skills needed to conduct effective independent research), structure, write and reference scientific essay.

The aims of this course are:

- To understand the concept of X-ray imaging, its challenges, benefits and risks.
- Develop transferable skills:
    - Conducting independent research
    - Critical analysis
    - Writing and presentation of thoughts and ideas.
- First-hand experience of university-style teaching and work involved.
- Give you an opportunity to experience how science can be used to solve real-world problems

Uni Pathways Mark Scheme 2020

	Subject Knowledge	Critical Thinking	Written Communication
1st	The work shows a depth of knowledge and understanding of key concepts and scientific methods, through engaging with relevant sources. Knowledge is used to build and support highly effective scientific arguments and explanations.	Analyses key scientific evidence, arguments, and reasoning. Interprets meaning and makes connections. Identifies and critically evaluates key scientific arguments and evidence, deciding on their credibility, strength, and relative significance, drawing convincing conclusions.	The work has a coherent flow and is well structured. The writing style is appropriate; scientific language and key scientific terms are used accurately and effectively to support the arguments and explanations made. There are no, or very few, errors in spelling or grammar. Consistent referencing, appropriate paragraphing and use of correctly labelled tables and graphs matching the style taught in the course.
2:1	The work shows an understanding of key concepts and scientific methods, drawing on relevant sources. Knowledge is used to build and support effective scientific arguments and explanations.	Analyses relevant scientific evidence, arguments, and reasoning. Identifies and critically evaluates relevant scientific arguments and evidence, deciding on their credibility and strength, drawing reasonable conclusions. Shows some understanding of the relative value of evidence and arguments.	The work is well-structured. The writing style is appropriate; scientific language and key terms are used correctly. There are few errors in spelling or grammar. Mostly consistent referencing and use of tables and figures; matching the style taught in the course.
2:2	The work shows an understanding of key concepts and scientific methods, with no major misconceptions. Beginning to apply this knowledge to build and support effective scientific arguments and explanations.	Identifies and uses basic scientific evidence, arguments, and reasoning. Showing some understanding of the quality of scientific arguments and evidence. Not yet showing understanding of the relative value of evidence and arguments.	The work has some structure. The writing style can sometimes be informal; occasionally scientific language and key terms are not used when it would be appropriate to do so. There are some errors in grammar and spelling do not get in the way of communicating the content. Referencing has some consistency; matching the style taught in the course Limited use of tables and graphs.
3rd	Shows a developing understanding of key concepts and scientific methods, with some misconceptions. Does not yet apply this knowledge to build and support scientific arguments and explanations.	Beginning to analyse scientific evidence, arguments, and reasoning. Describes evidence and arguments, while not yet evaluating them.	The grammar, spelling, style, and structure of the work need improving in order to communicate ideas to the reader. Scientific language, key terms and references are not always used correctly. Limited, or no use of tables and graphs.

Baseline Assignment: Pupil Feedback Report

Name of Pupil	
Name of School	
Name of RIS teacher	
Title of Assignment	

How your assignment is graded:

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at A-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Marks

OVERALL MARK / 100		FINAL MARK / 100 (including any deductions)	
DEDUCTED MARKS		FINAL GRADE	

If marks have been deducted (e.g. late submission, plagiarism) the teacher should give an explanation in this section:

Mark Breakdown and Feedback

Subject knowledge	
	mark
Critical thinking	
	mark
Written communication	
	mark

Final Assignment: Pupil Feedback Report

Name of Pupil	
Name of School	
Name of RIS teacher	
Title of Assignment	

How your assignment is graded:

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at A-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Marks

OVERALL MARK / 100		FINAL MARK / 100 (including any deductions)	
DEDUCTED MARKS		FINAL GRADE	

If marks have been deducted (e.g. late submission, plagiarism) the teacher should give an explanation in this section:

Mark Breakdown and Feedback

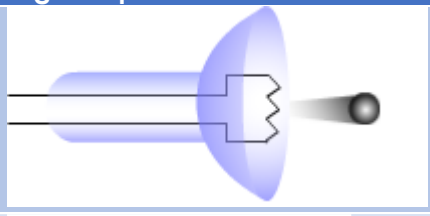
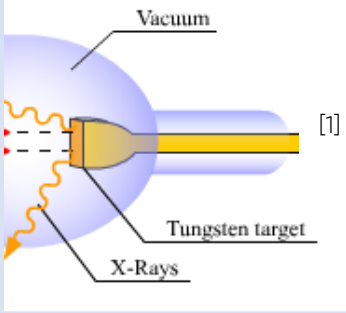
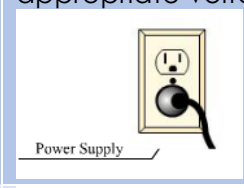
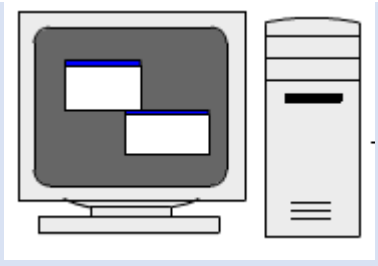
Subject knowledge	
	mark
Critical thinking	
	mark
Written communication	
	mark

Subject Vocabulary

Word	Definition	In a sentence
Artifacts	Avoidable, not useful information in the image that has a negative impact on the image quality (i.e. operator's ability to locate and identify objects within an image).	This is comparable to having a bad aerial or satellite reception and you get all sorts of lines and distortions on your TV when you are trying to watch something.
Attenuation	Reduction in the intensity of an X-ray beam as it passes through matter.	A real-world example of attenuation in action is when your Wi-Fi signal (internet) is getting significantly weaker the further you/your device is from the router.
Beam Hardening	Preferential removal of low energy X-ray photons as they pass through matter.	An analogue is getting a pack of M&M's and always removing the red ones before eating the rest.
Collimator	Is a device (made from lead) that enables you to limit the spread of the beam to a particular area or shape it into a particular form such as a fan or a ring.	Using a lens or a magnifying glass to focus sunlight into a spot on a surface.
Dynamic range	Represents a spread (from min to max) of X-ray intensities that a detector can differentiate between.	Using eyes as an example, this is the ratio between us being able to see in the brightest light during the day and on the darkest of the nights.
Focal spot	An area within the X-ray tube which is struck by electrons and from which X-ray are emitted.	An area on your torch from which light is shining when you turn it on.
Ionising Radiation	Radiation that can remove electrons from atoms of the material that it is passing through, causing the atom to become charged (ionised).	Gamma rays, X-rays and ultraviolet are examples of ionising radiation, which, when interacts with living cells, can cause mutation, increasing the risk of cancer.
Morphological Features	External or internal features that are specific to a given object and would help to describe, identify it in the image.	An example of morphological features of objects in the suitcase includes location, shape, size and orientation.
Orthogonal View	A way of representing a 3D object in a 2D drawing. Each view represents an exact shape of the object seen from a given side.	Example of orthogonal view is a drawing that you did of your house whilst looking straight down at it from the top.
Phantom	Complex structure containing one or more samples and is designed to highlight/test specific ability or features of the system.	An analogue of this is a benchmark test for your PC or console, as well as game or movie trailer.

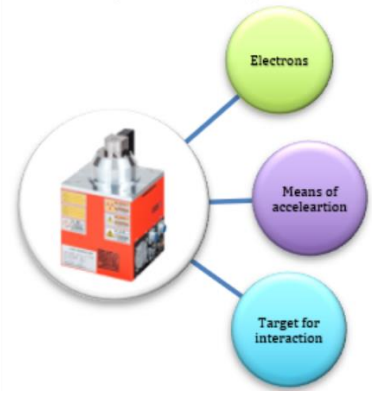
Raster scan	A rectangular pattern of image capture, where the X-ray beam is swept from left to right in a zig-zag pattern over the area of interest.	A beam is swept across the area of interest row by row, in a snake-like motion.
Sensitivity	The ability of the system to correctly identify a threat when there is one.	Being able to find an apple in your bag that you have placed there in the morning.
Signal-to-Noise Ratio (SNR)	This is a measure that compares the ratio of the desired signal to the level of background noise. The higher the SNR value, the better.	A measure of how easily a message can be disrupted by meaningless chatter.
Spatial Resolution	Refers to the imaging system's ability to differentiate between two objects.	Low spatial resolution refers to the inability of the system to distinguish between two objects that are close together.
Specificity	Ability of the system to correctly detect no threat when none is present.	This is equivalent to you being able to look through your bag and establish that you have no apple hidden in there.

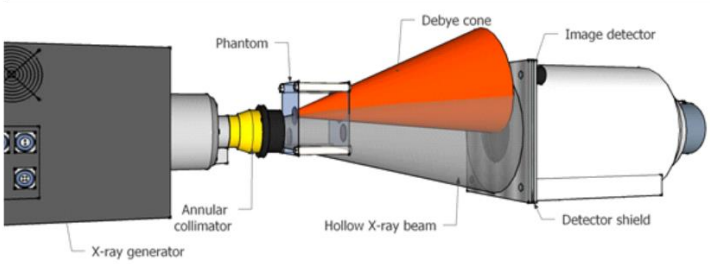
Knowledge Organiser

A typical X-ray system has the following components:		
X-ray tube	**Cathode** (filament) – source of electrons. Negatively charged. Heats up and ejects electrons. The filament is powered by alternating current, from a transformer. Varying the current will control the amount of X-rays being produced and	 [1]
	Anode (target) – positively charged. Has the following functions: • provides a complete circuit for purposes of accelerating the electrons. • houses the target material. • cools the tube → if not address the target would melt. Selecting correct material for Target is important → provides means for electron interaction. High-density materials (e.g. copper, cobalt, tungsten) provide sufficient atomic mass for electron interaction.	 [1] [1]
High voltage power supply	Changing the X-ray machine current or voltage settings alters the properties of the X-ray beam. Increasing the current will increase the number of X-rays being produced (i.e. more electrons delivered to target). Changing the voltage will increase the velocity of electrons as they hit the target. Electron with higher velocity = greater energy of the produced radiation = greater penetrating power of X-rays.	Filament → uses small voltage supply (mV). Anode → large voltage supply to accelerate the electrons. Transformer is used to supply the appropriate voltages.  [1]
Control unit	Allows to control the operations of the X-rays system. In most basic form offers the following controls: current, voltage and timer.	 [1]

[1]

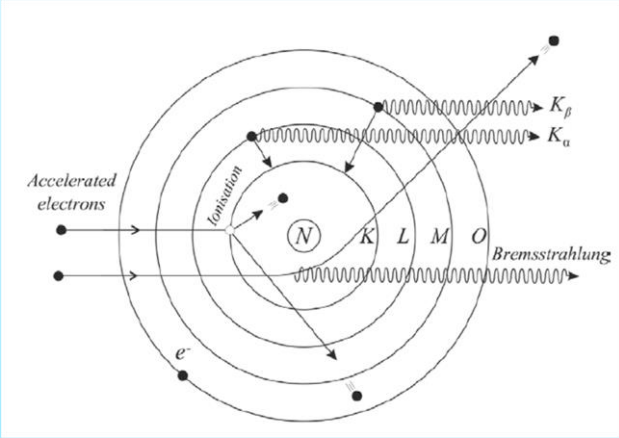
X-ray generator provides three things needed to produce X-rays





X-rays are generated via interactions of the accelerated electrons with the electrons within the nuclei of the material in the target.

As a result → two types of X-rays are generated:



Bremsstrahlung

- Breaking radiation
- Emitted when high-speed electrons ejected from the filament (i.e. cathode) are decelerated when they strike the target (i.e. anode)
- Responsible for 80 % of total X-rays produced.
- Very limited use.

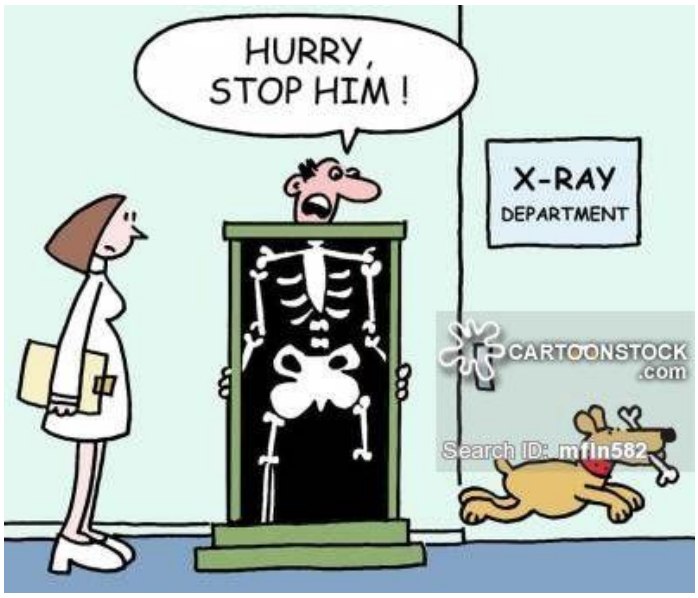
Characteristic radiation

- Occurs when accelerated electrons collide with inner shell electron of the target.
- When the incident electron energy is higher than the energy that holds the inner shell electrons → both are ejected, leaving a vacancy.
- The vacancy is then filled by an outer shell electron → excess energy is released as characteristic radiation.

	STANDARD	DUAL-ENERGY	BACKSCATTER	CT
	SINGLE VIEW	SINGLE / DUAL VIEW	SINGLE VIEW	3D
Material discrimination	✗	✓	✓	✓
Threats detected				
Precision				
Throughput	FAST	FAST	VARIES	SLOW
Benefits	• Low cost	• Distinguish between materials and color-code for operators • Can detect explosives hidden behind object made of heavy materials	• Distinguish between low Z elements • Generates 2 images	• Great spatial resolution (up to a few millimeters) • Looks past/around high-density objects
Limitations	• Can't distinguish between various absorbing materials • Tend to have higher false alarm and overlooked threat rates	• Can't distinguish as effectively between lighter elements	• Reduced penetration (esp. through high density materials) • Expensive, esp. if 2-sided version needed.	• Slow throughput • High costs
Cost (estimated)	€	€€	€€€	€€€

[2]

Tutorial 1 – Introduction to X-rays



[3]

What is the Purpose of Tutorial 1?

- Introduce you to X-rays, their discovery and notion of X-ray imaging.
- Discuss what makes X-rays useful to help solve real-world problems and touch on some of the challenges associated with using X-rays.
- You will also learn that X-rays play an important part in a number of different industries beyond the widely known medical field.

Learning outcomes

By the end of the tutorial, you should be able to:

- Know how X-rays were discovered and their primary use.
- Be able to provide reasons that make X-rays useful to solve problems outside the medical field.
- List three areas of the industry where X-rays are used and how they benefit from them.

Activity 1 – What is it?

In pairs, discuss what you think X-rays are. Record your ideas in the box below. From the list choose and share 1 or 2 ideas with the class.

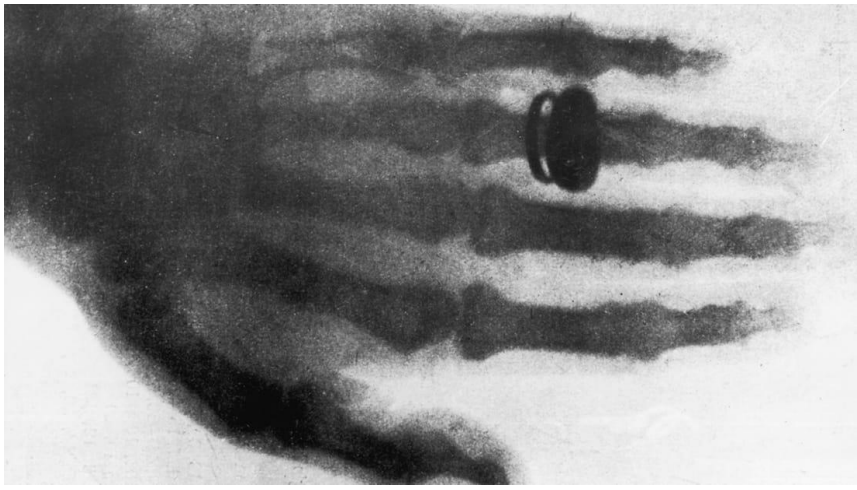


Figure 1 [4]

Looking at Figure 1, please answer the following questions in the box below:

- What is this an image of? How do you know?
- Can you list three different things that you can see in this image?
- How can the information that you can get from this image be useful?

Record your answer in the space below.

Activity 2 – How was it discovered?

Watch Video 1 and use space below to make notes in the box below. Link:
https://www.theguardian.com/science/video/2013/apr/19/x-ray-vision-discovery-medicine

After Watching Video 1, please use the space below to answer the following questions:

- Who discovered X-rays?
- What does X in X-ray mean?
- List 4 things that X-rays can do and how you think this is useful?
- Name one thing X-rays can help cure and cause at the same time?

Which of these statements do you think is true?

1. X-rays revolutionised the treatment of tuberculosis.
2. X-rays helped discover the structure of DNA.
3. Ultrasound and MRI imaging are X-ray based techniques.
4. X-rays were used to by shoe stores to help them ensure better shoe fit.
5. X-rays are harmless.
6. X-rays can come from natural sources.

Activity 3 – Why do we need it?

Watch Video 2 on X-ray applications. After watching the video, in pairs, discuss and suggest one other application for X-rays not mentioned in the video, supporting your answer with reasons as to why you think it is useful. Record your answer in the space below.

Link: https://www.youtube.com/watch?v=ToXyrzuVsXY

Why was this X-ray image taken?

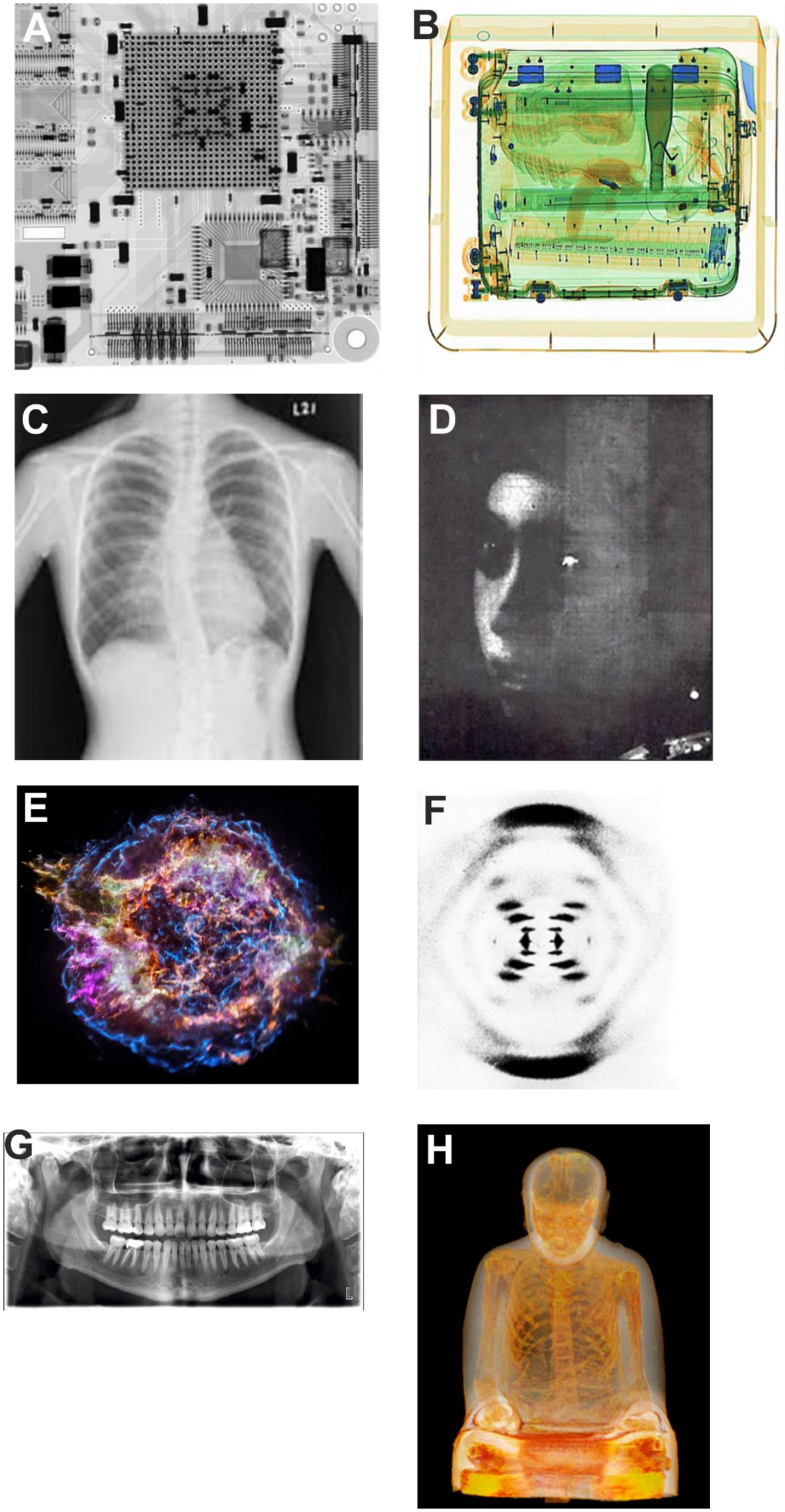


Figure 2 - [5–8]

Looking at the images shown in Figure 2, identify the reason behind each one of them being taken. Record your answers into the table below.

Image	**Application identified**
A	
B	
C	
D	
E	
F	
G	
H	

Tutorial glossary

Use this space to write down any words you have learned today

Word	Definition	In a sentence

Notes

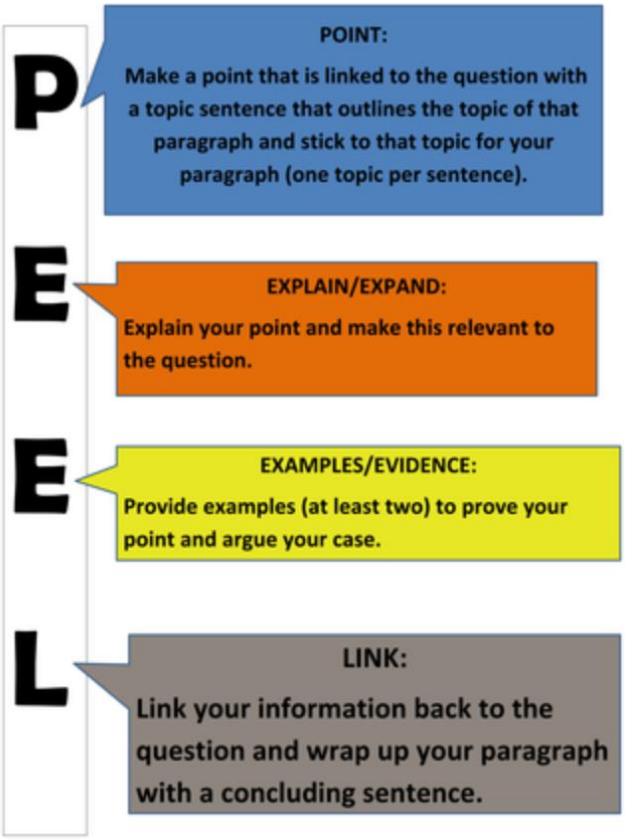
Homework 1

Look back at the tutorial and if you think it is necessary, use additional sources of information to help you formulate the answer to the following question: **What are X-rays**?

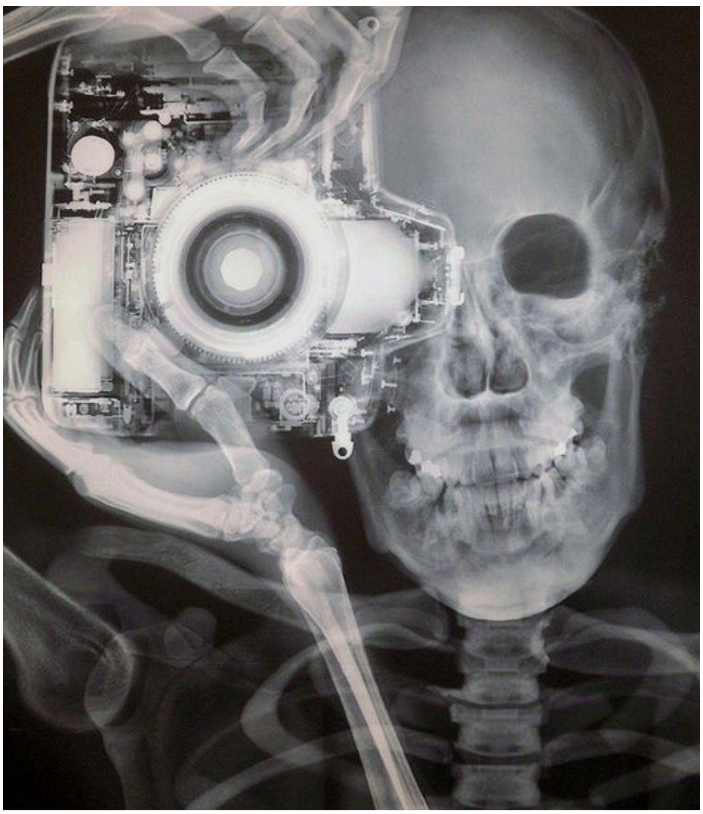
Write **400-500 words** to answer the question (i.e. What are X-rays). As part of your answer, you **must** also cover the following:

- Explain of the events that lead to 1st X-ray image being a result of a scientist experimenting on his wife (who and how discovered it).
- What is the difference between light (i.e. sunlight) and X-rays?
- Describe applications of X-rays and give supporting evidence of how and why they are useful for the given task.

I am looking forward to reading your thoughts and ideas. Remember to structure your answer, make your points clear, expand and support them with evidence, explaining how they are relevant and help you answer the question. Follow the PEEL model below to help you organise your writing.



Tutorial 2 – Are X-rays and Visible light the same thing?



[9]

What is the Purpose of Tutorial 2?

- This tutorial focuses on developing an understanding of what X-rays are, what is and how they fit within the Electromagnetic spectrum.
- We will cover the main components of the X-ray sources and discuss why and how they come together to produce a beam of X-rays.
- All this information will enable you to describe the principles behind the production of an X-ray image.

Learning outcomes

By the end of the tutorial, you should be able to:

1. Know and be able to explain how X-rays are different from visible light.
2. Explain what Electromagnetic Spectrum is. Demonstrate your knowledge by being able to describe the relationship between energy, wavelength, and frequency within the Electromagnetic Spectrum.
3. Know the main component parts of an X-ray source, understand and be able to describe how they all come together to produce X-rays
4. Understand and be able to describe the fundamental principles behind the production of a typical X-ray image.

Activity 1 – Introduction to X-rays

At the start of this tutorial, you will be given a 15 min University style presentation on the topic of X-rays.

As we are going through the presentation, think of **two questions** (related to the content of the presentation) that you would like to ask during the **Q&A session.**
Write your questions down into space below. For example, this can include anything you are not sure about, need further clarification or explanations on.

Q&A session – Question 1

Q&A session – Question 2

Notes

Discuss the following questions in pairs and write your ideas in the boxes below.

1. **What is the Scientific name for Figure 3?**

2. **In one sentence, describe what Figure 3 represents.**

3. **Fill in the gaps in Figure 3**

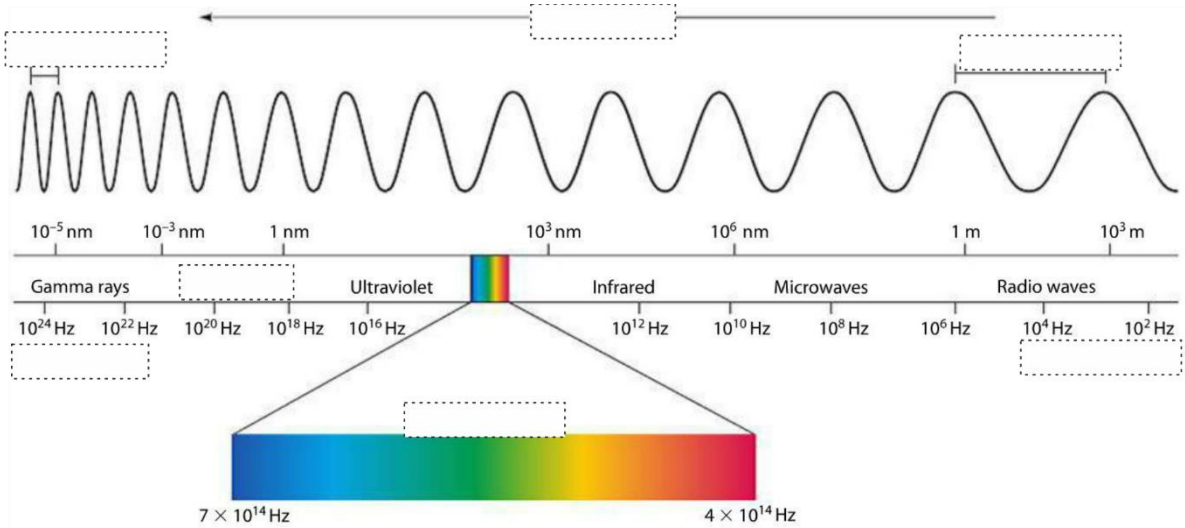


Figure 3 – diagram to complete. [9]

4. **Looking at the diagram identify three trends:**

   1. ……

   2. ……

   3. ……

5. **How does the behaviour of different radiation in Figure 3 make them suitable for a range of uses?**

Activity 2 – X-ray production

Using the information obtained from the introduction presentation and after watching the "X-ray production" video here complete the section below.

1. **Name the device shown in Figure 4 and label the missing components.**

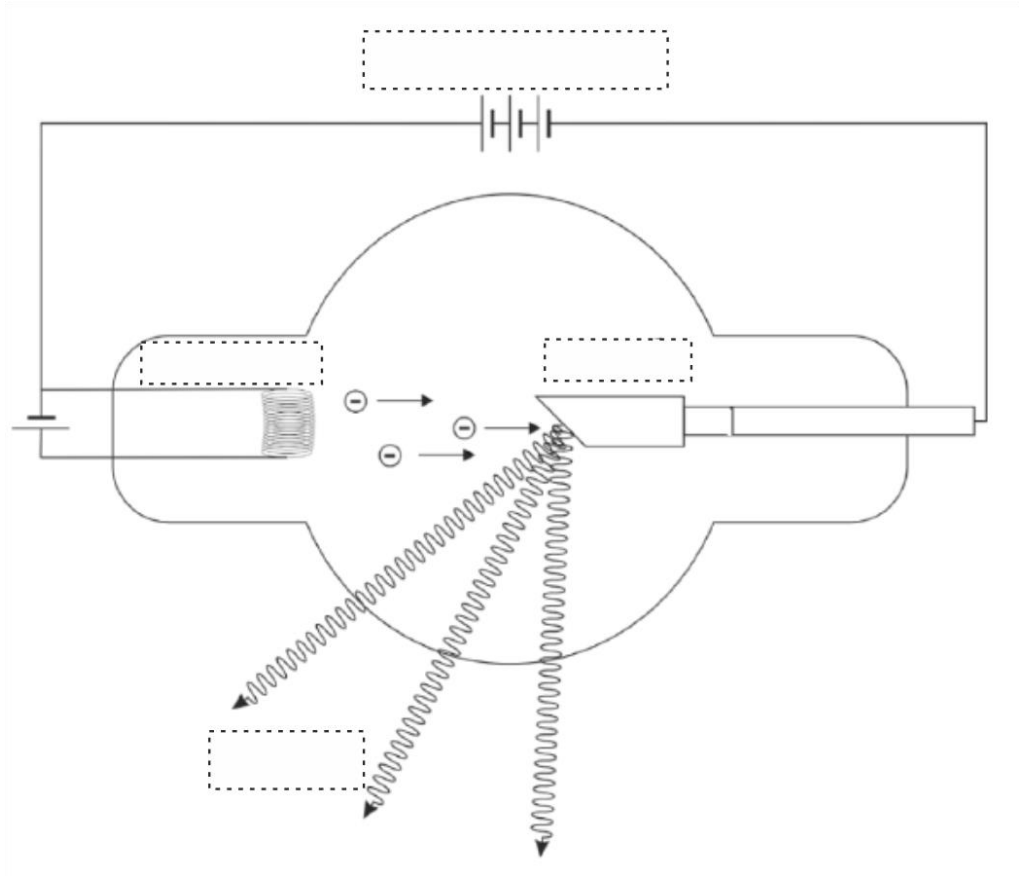


Figure 4 – Unlabelled X-ray system component [10]

Name Figure 4……

2. **Using the components, you have labelled in Figure 4, in 4 steps describe how X-rays are produced.**

   1. ……
   2. ……
   3. ……
   4. ……

3. **Can an old CRT TV produce X-rays?**

4. Calculate what happens to wavelength of X-rays if you change the Anode material to 8.047 keV, 17.479 keV, 59.318 keV. How will this impact the X-rays generated by the X-ray source (consider wavelength, energy, and penetrating power)? Which one would you use in the X-ray source that will be deployed to scan suitcases?

Prefix	Symbol	Meaning
Tera-	T	10^{12}
Giga-	G	10^{9}
Mega-	M	10^{6}
Kilo-	k	10^{3}
Deci-	d	10^{-1}
Centi-	c	10^{-2}
Milli-	m	10^{-3}
Micro-	µ	10^{-6}
Nano-	n	10^{-9}
Pico-	p	10^{-12}

$$E = \frac{hc}{\lambda} \quad \therefore \ \lambda = \frac{hc}{E}$$

where:

h=$6.626\times10^{-34}\,Js$

$c = 299792458\ \mathrm{ms}^{-1}$

λ=wavelength of X-ray photon (nm)

E=energy of a photon (J)

1keV = 1.602×10^{-16} J

5. **State the effect of the following two parameters on the X-ray beam:**
    a. Voltage: ……..
    b. Current: ……..

6. **Label each of the components in the 3D diagram below (Figure 5). Also:**
    a. Give a brief description of their purpose.
    b. Why do you need to focus the X-ray beam? How do you achieve this?

Figure 5 – 3D diagram of X-ray imaging setup

Activity 3 – X-ray image production

Using the information obtained today, in your own words, summarise how an X-ray image is produced.

Tutorial glossary

Use this space to write down any words you have learned today

Word	Definition	In a sentence

Additional resources:

1. https://www.nde-ed.org/EducationResources/HighSchool/Radiography/xraygenerators.htm
2. https://www.youtube.com/watch?v=dBFGjdgbpno
3. https://www.youtube.com/watch?v=7v2gs8rdQzU
4. https://www.youtube.com/watch?v=T1WwHh4b__M

Notes

Homework 2

Look back at the tutorial and if you think it is necessary, use additional sources of information to help you formulate the answer (200-300 words) to the following question:

What are the similarities and difference between X-rays and visible light, and what is the relationship between their respective energy, wavelength, frequency?

Key points to consider:

1. Electromagnetic spectrum.
2. Energy.
3. Wavelength.
4. Frequency

Notes

Tutorial 3 – Are X-rays the answer to Airport security?

[11]

What is the Purpose of Tutorial 3?

- This tutorial focuses on developing your understanding of how technology can be used to solve real-world problems, such as those within the Airport security setting.
- In this section, you will be introduced to the notion of layered security, including different techniques, technologies, and approaches that it incorporates.
- We will discuss the reasoning behind what makes X-rays very beneficial for security and the principles behind the two main workhorses of the industry,

Learning outcomes

By the end of the tutorial, you should be able to:

- Be able to describe different security layers and technologies employed at the airport.
- Describe and justify how and why X-rays are used in the airport security environment.
- Know the two main X-ray scanners for checkpoint security and explain the principles behind their operation (including applying theory from Tutorial 2).

Activity 1 – Why use X-rays in a security setting

You cannot distinguish between cheese and explosives in a typical X-ray image. See Figure 6.

Figure 6 – Dual-energy and visible light images of a suitcase containing cheese and explosives.

Based on the information given above, in pairs, discuss if you would use an X-ray system for security screening?

If yes – why? If not – why not? Write your arguments in the space below.

Activity 2 – Layered security principle

Which one of these approaches do you think is used by airport security?

Approach	Used (yes/no)
Background check	
Observation	
Profiling	
Sniffer dogs	
Documents check	
Metal detectors	
No-fly list check	
Intelligence	
Pat-down	
X-ray screening	
Manual search	
Video surveillance	
Search of phone content	
Search of HDD content	
Reinforced cockpit door	
Highly trained staff	
Armed officer disguised as passenger	
Designated "incident" airports	
Sniffer cat	

Now arrange your chosen approaches into the following categories:

Category	Approach
Before arriving at the airport	
At the airport	
Inside the plane	

Watch the videos below, discuss and complete the tasks that follow.

Video 1 - https://youtu.be/cPyyv5iN76A

Video 2 - https://www.youtube.com/watch?v=bXNbe_jsoMg

Video 3 - https://www.youtube.com/watch?v=2Y4Gtiz4pQQ

What is layered security? Give your reasons as to why it is required?

With you partner, discuss if there is a relationship between cost and security. Give your opinion on the impact (if at all) of this on the airport security.

Now follow the path that a typical traveller would take when queuing to go through the security at the airport.

As you move through the airport security, <u>identify the security features</u> that are being deployed and give a <u>brief outline for each</u> one.

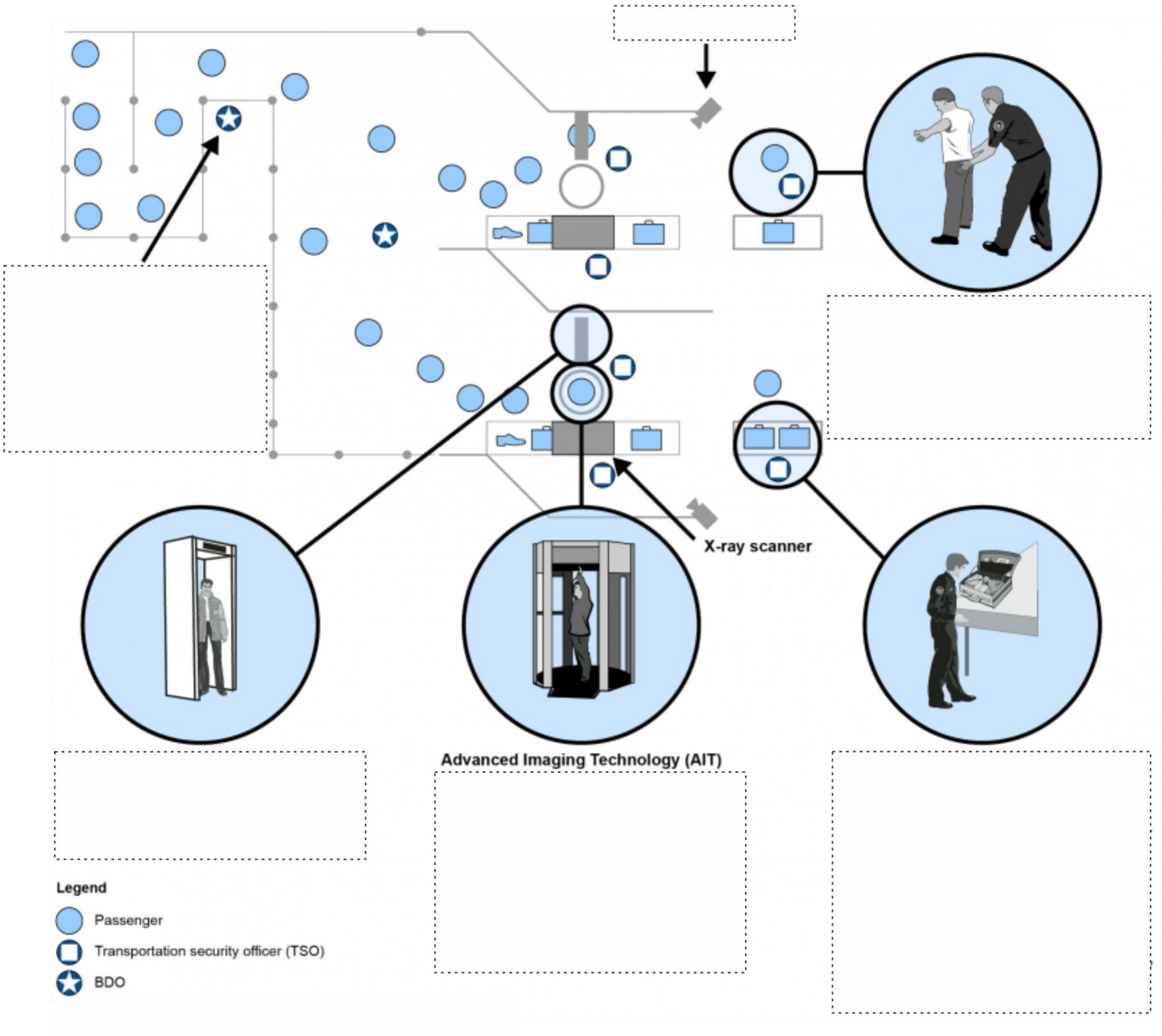


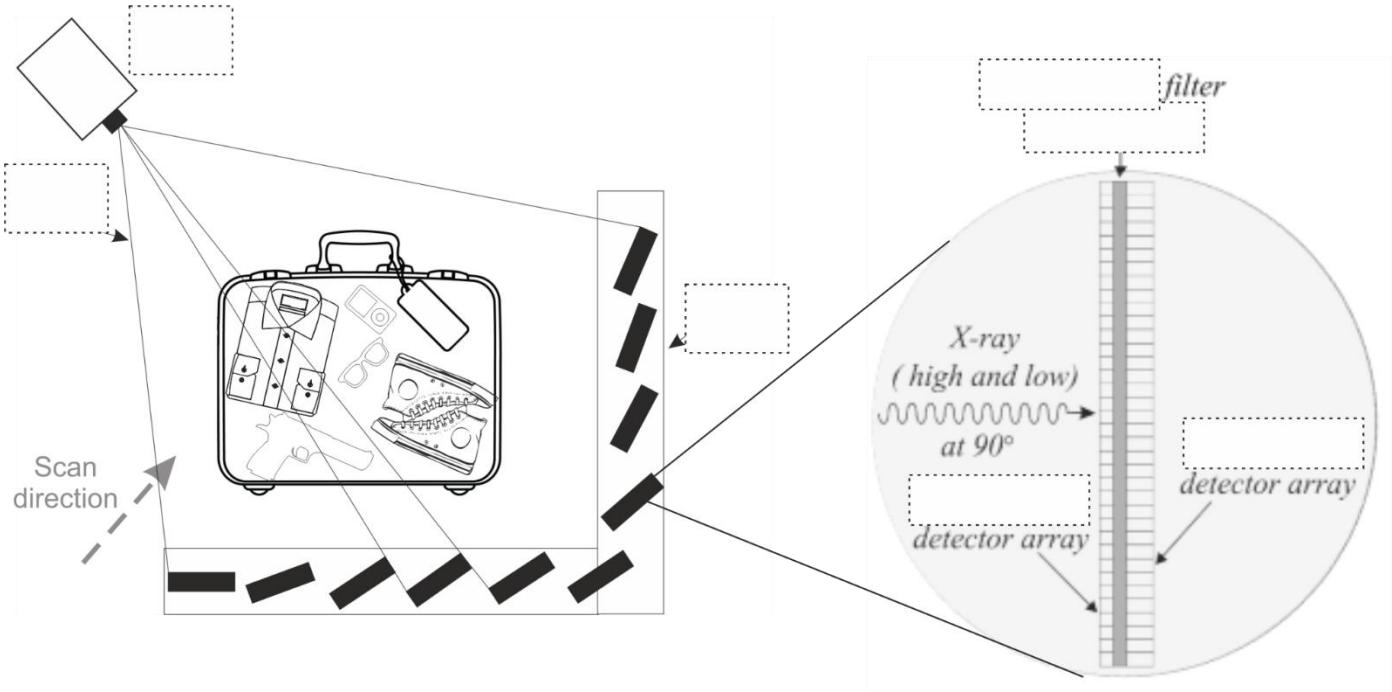
Figure 7 – Typical airport security route. [12]

Notes

Activity 3 – Workhorse of the industry

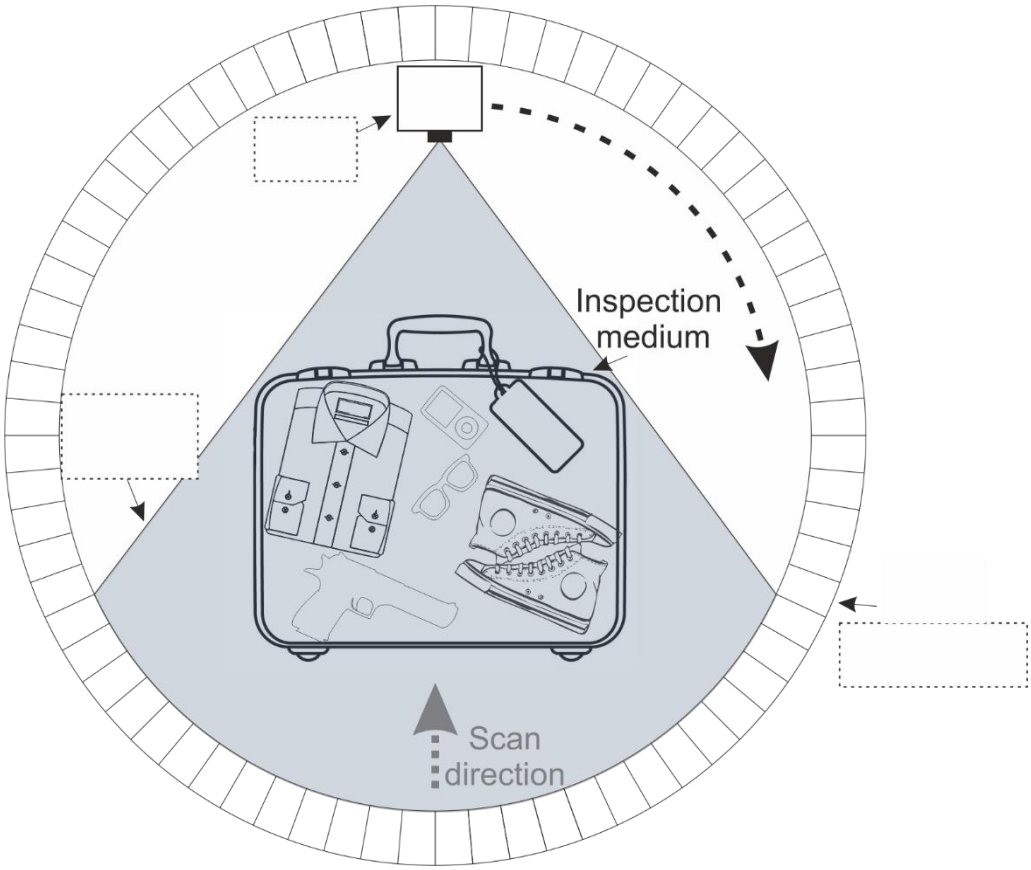
Name the two main X-ray scanners used in airport security:

Label the components of the Dual-energy X-ray system below.



Describe how Dual-energy X-ray system works (use your knowledge from Tutorial 2)

Label the components of the Computer Tomography (CT) X-ray system below.



Describe how Computer tomography X-ray system works (use your knowledge from Tutorial 2. here)

Critically evaluate each of the following technologies by completing the table below.

Screening technique	Advantage	Disadvantages
Sniffer dogs		
Dual-energy X-ray system		
Computer tomography (CT)		

Notes

Tutorial glossary

Use this space to write down any words you have learned today

Word	Definition	In a sentence

Additional resources:

- https://science.howstuffworks.com/transport/flight/modern/airport-security4.htm
- https://www.youtube.com/watch?v=IcWjZbXiFkM&t=164s
- https://www.youtube.com/watch?v=G2NJ_isQOkw

Notes

Homework 3

In preparation for Tutorial 4 use the resources mentioned below to help you answer the questions.

- Appendix 2 – Introduction section
- Appendix 2 – Dual-energy X-ray imaging section
- https://www.youtube.com/watch?v=Kuhc6od_huU
- https://science.howstuffworks.com/transport/flight/modern/airport-security4.htm
- https://www.youtube.com/watch?v=G2NJ_isQOkw

Remember to structure your answer, make your points clear, expand and support them with evidence, explaining how they are relevant and help you answer the question.

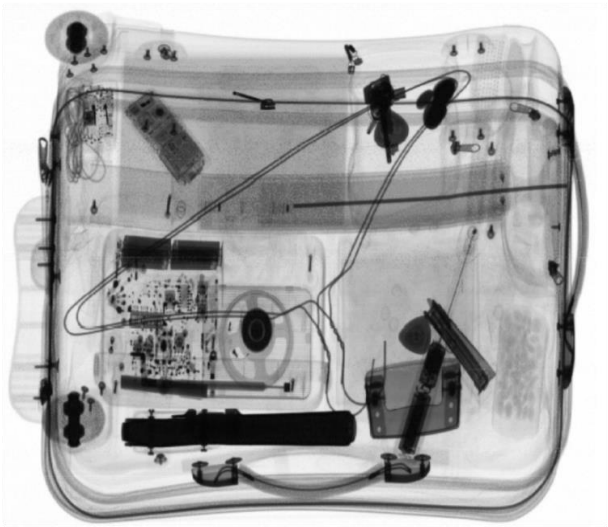
Questions:

1. **Why is there a need to screen passengers, luggage and cargo?**

2. **What do you think is the weakest link in airport security? Support your point with evidence.**

3. **How important is the training of the X-ray system operator (i.e. observer)? Discuss the ways that the operator's performance can be improved.**

4. **What are the challenges associated with identifying threats in this X-ray image? What would you do to/change in the image to improve your ability to identify threats?**



5. **Complete the table below.**

X-ray system	Similarities	Differences
Dual-energy X-ray system		
CT (computer tomography)		

Tutorial 4 – DEXI vs. CT

Figure 8 – radiation doses received from different things. [13]

What is the Purpose of Tutorial 4?

This tutorial builds on the information you have learned during the last three tutorials and links them together, We will look at how both Dual-energy X-ray Imaging system (DEXI) and CT have not replaced each other and are still active components in the security hierarchy. We will discuss in detail the advantages and disadvantages of each system, as well as associated risks and their mitigation strategies.

Learning outcomes

By the end of the tutorial, you should be able to:

- Be able to justify the use of DEXI and CT at the airport.
- Know the similarities and differences between the two scanners (i.e. DEXI and CT) and their position within the airport security hierarchy. This knowledge will help you formulate an evidence-backed argument as to why DEXI is not replaced by CT.
- Have a clear understanding of advantages, disadvantages and risks of each of the scanner, enabling you to critically evaluate a system, supporting your discussion with evidence

Activity 1 – Dual-energy vs. CT, or Dual-energy plus CT?

Following the presentation and using the information that you have prepared in advance of this session (i.e. homework at the end of Tutorial 3), answer the questions below. Discuss in pairs and then record your answer below.

List and describe the <u>similarities</u> between Dual-energy and CT systems.

List and describe the <u>differences</u> between Dual-energy and CT systems.

Which one of the two systems would you recommend for Airport security and why? Support your statements with evidence (consider the advantages and disadvantages of each).

Activity 2 – Risk vs. Reward?

Arrange the activities in the order of radiation exposure that you will receive.

- Eating Banana
- Taking a flight
- Using the X-ray Scanner
- 1 regular day on Earth

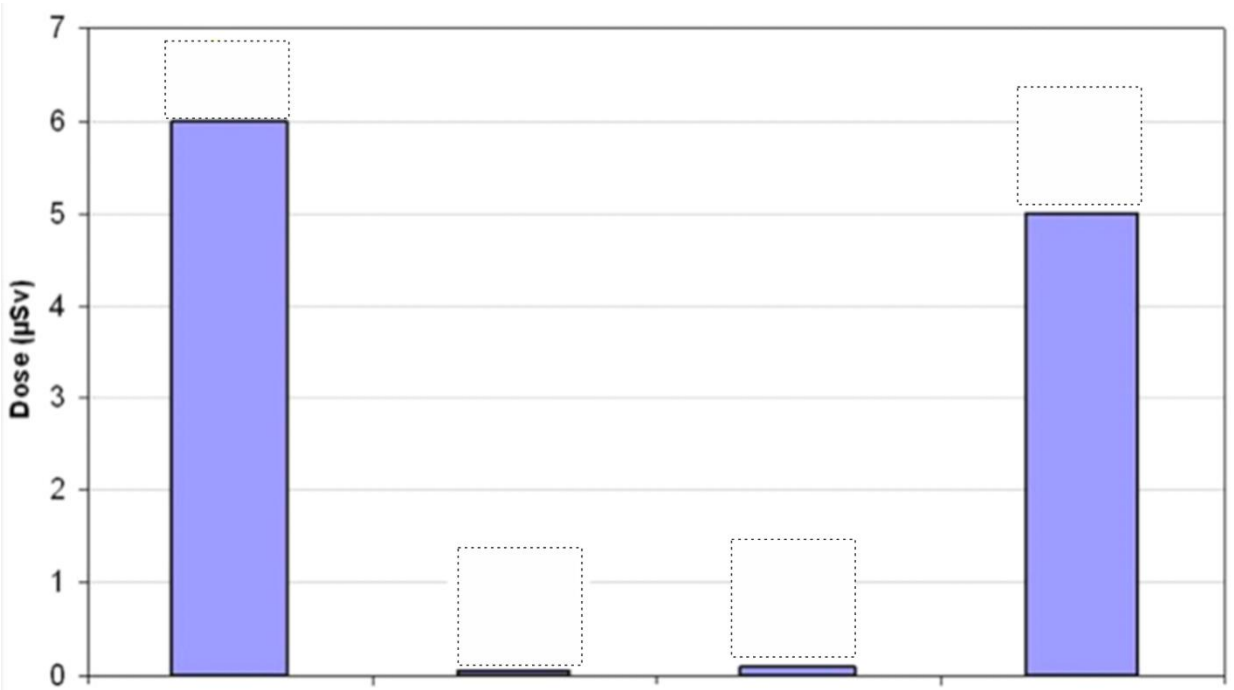


Figure 9 – comparison of the dose received subject to radiation exposure in mSV from different activities. [14]

Watch the video https://www.youtube.com/watch?v=YHJzdu9Uf8Q. Describe what the diagram below shows, how this relates to X-ray and how can this be applied to reduce the risk from X-ray radiation.

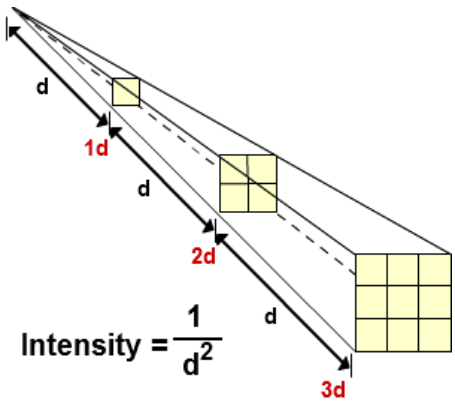


Figure 10 - [15]

Using the information learned from above calculate how the intensity of the X-rays for Woman A and B. Did the intensity change? How does this impact the amount of ionising radiation (i.e. X-ray dose) that they will receive? Use the following information for your calculation:

- **X-ray system dose (intensity) = 0.01 μSv**
- **Person A = 1 m distance**
- **Person B = 4 m distance**

Figure 11 – Image of X-ray scanners in an Airport security setting. [16]

10,000	Fatal within weeks
6,000	Typical dosage recorded in those Chernobyl workers who died within a month
5,000	Single dose which would kill half of those exposed to it within a month
1,000	Single dose which could cause radiation sickness, nausea, but not death
400	Max radiation levels recorded at Fukushima plant 14 March, per hour
350	Exposure of Chernobyl residents who were relocated
100	Recommended limit for radiation workers every five years
10	Dose in full-body CT scan
9	Airline crew NYC -Tokyo polar route, annual
2	Natural radiation we're all exposed to, per year
1.02	Radiation per hour detected Fukushimia site, 12 March
0.4	Mammogram breast x-ray
0.1	Chest x-ray
0.01	Dental x-ray

Figure 12 – Radiation exposure and how it compares. [17]

Looking at the diagram above do risks of using X-rays outweigh the advantages? If so, how? If not, why not?

If you have a system with key advantages, but it also has some disadvantages and health risks, would you use it? What can you do to make it work? How can you balance these three things?

Tutorial glossary

Use this space to write down any words you have learned today

Word	Definition	In a sentence

Additional resources:

- See Appendix 2 for additional reading on Dual-energy and CT systems
- https://www.astrophysicsinc.com/4-x-ray-technologies-that-will-make-you-a-security-expert/

Notes

Homework 4

Look back at the tutorial and if you think it is necessary, use additional sources of information to help you formulate the answer (300-400 words) to the following:

Looking at the image in Figure 13:

Figure 13 – Image of entrance into the county courthouse in the USA. [18]

1. **Identify** which of the two **scanners** (i.e. Dual-energy or CT) you think would be the most beneficial for this setting and discuss the **reasoning behind your decision**.
2. **Identify** the **challenges** that would be faced by security in this environment (see photo) and describe how the scanner you have identified can be used to help solve those. **Support** your **answer** with **evidence** and clear **reasoning**.

Tutorial 5 – Final Assignment

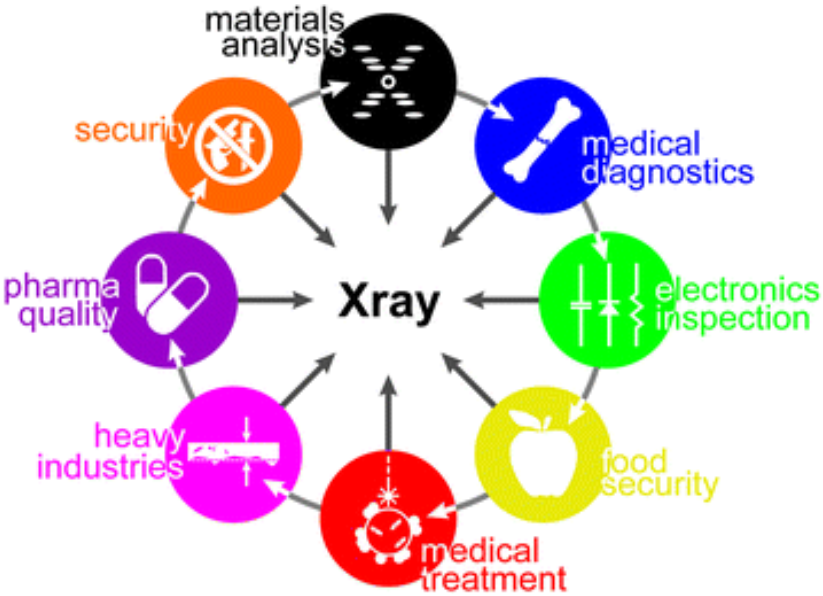


Figure 14 – uses of X-ray imaging [19]

What is the Purpose of Tutorial 5?

Throughout this tutorial series, you have been introduced to the notion of X-ray imaging, its role and place within the hierarchy of Airport security screening. At this point, you are well aware that this technology, just like many others has its risks and benefits, which depending on the specific requirement, can outweigh each other.

It is important to remember that a real-world system (e.g. X-ray security scanner) is subject to optimisation function of different parameters and develop an understanding that these change depending on the requirement of the area that the technology is going to be applied in.

Learning outcomes

By the end of the tutorial, you should be able to:

- Know the relationship between X-ray energy, penetration power, image quality and dose.
- Describe the requirements of a scientific report and produce one.
- Know what good diagram looks like and be to apply this to help support and enrich your narrative/arguments.
- Know the importance of appropriate scientific sources and different styles to reference them within your work.
- Correctly apply jargon/scientific vocabulary to describe the scientific theory in your report.

Activity 1 – System Optimisation

After the discussion, indicate the relationship between the four parameters below.
Suggested linking words include: increases, decreases, same.

X-ray energy	Image quality
Penetration power	Dose

After discussion, summarise how you would control the dose.

Can you have all four conditions (i.e. X-ray energy, image quality, penetration power, dose) at optimum? If yes, how? If not, why not?

In pairs, discuss how you would improve the image quality of your system and maintain the penetration power. Support your suggestions with evidence backed reasoning. Record your answer below.

Activity 2 – Critical review

Choose one of the X-ray scanners (i.e. Dual-energy or CT) and prepare your argument on why you think it is the most suitable. Use the table below to help formulate your answer. After discussion, use the notes section below to record any additional points/changes to your original answer.

For	Against

Benefits	Challenges

Risk

Notes

Activity 3 – Writing a Scientific Report

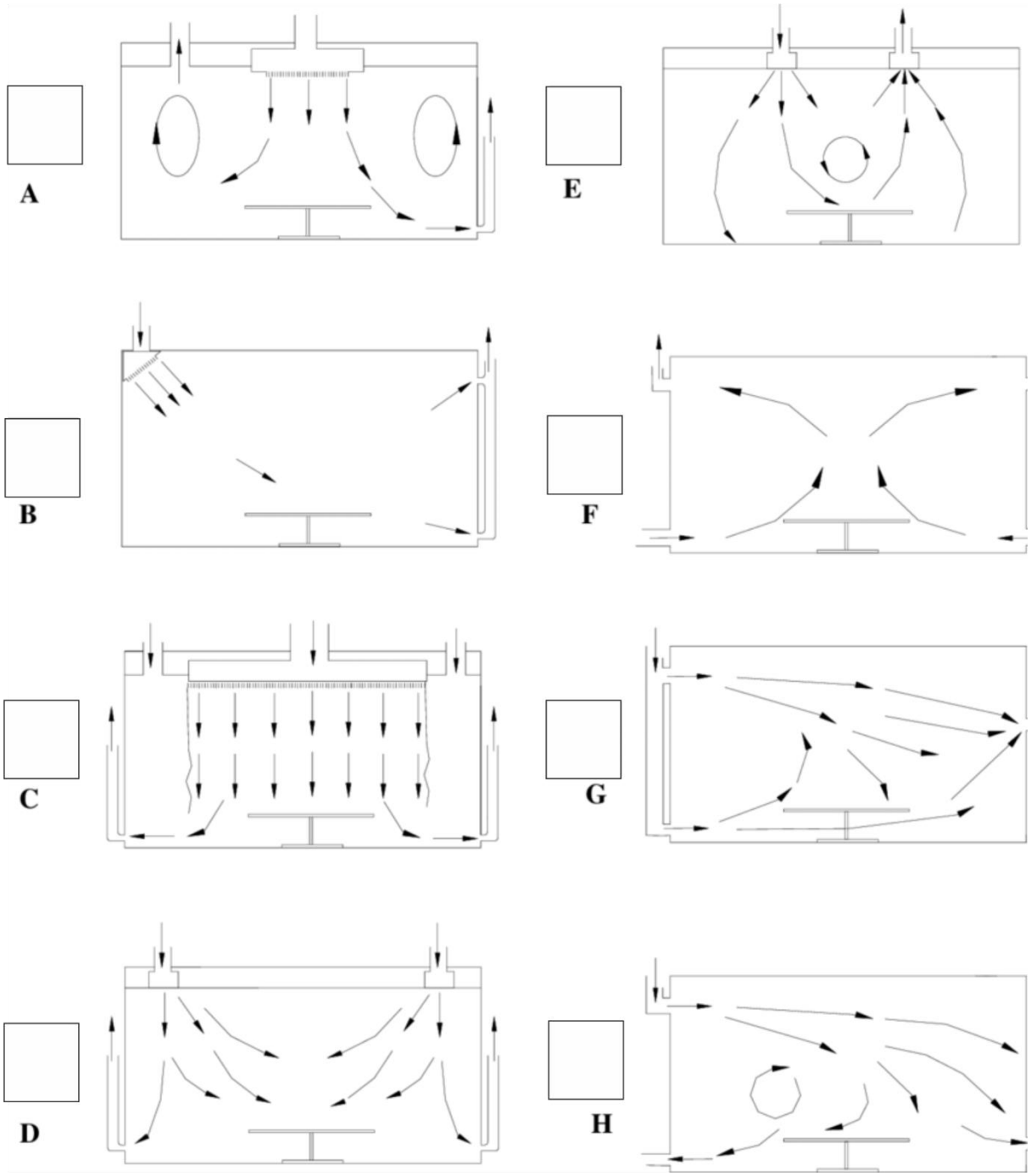
Discuss what a good and bad scientific report looks like. Record the findings from your discussion in the space below.

Write down 5 things that makes a report:

Good	Bad
1	1
2	2
3	3
4	4
5	5

Read the handout here. Identify what a typical structure of the report should look like. Highlight the ones that you will include in your report and provide your reasoning (i.e. why you are including them).

Looking at the diagrams below identify the ones which, in your opinion, represent a good scientific diagram.



[20]

Identify what is missing from the diagrams above

Summarise what a good and high-quality scientific report should look like (e.g. structure, diagrams, content).

Discuss what makes a source of information a good source? How do we know what it looks like? Write the outcomes of your discussion into space below.

Tutorial glossary

Use this space to write down any words you have learned today

Word	Definition	In a sentence

Additional resources:

- https://www.3dx-ray.com/2010/01/01/x-ray-scanning-optimising-systems-security-services/
- http://xrayphysics.com/attenuation.html
- https://www.compoundchem.com/2014/04/02/a-rough-guide-to-spotting-bad-science/
- https://www.youtube.com/watch?v=HElwooECl2Y
- https://writingcenter.unc.edu/tips-and-tools/scientific-reports/

Homework – Final assignment

Final Assignment title

Airport Security – using X-ray vision to identify hidden weapons and explosives.

Details of final assignment:

Produce a scientific report (**2000 words**) covering **one** of the X-ray based systems used for security screening.

Your scientific report should **include**:

- An introduction to X-rays and how they are produced.
- Why security screening is required; security screening challenges and how X-rays can help solve them.
- Select one of the two systems (Dual-energy X-ray Scanner or Computer tomography (CT) scanner) and describe their basic principle of operation.
- Critically evaluate your chosen security scanner. Provide a balanced, evidence-backed argument on the benefits, challenges, and risks that this system (scanner you selected) brings to the security industry? Try and approach this discussion from security, airport, and members of the public perspective (are these different? If so, how?). How are the challenges and risks addressed within the system?
- A conclusion summarising why your system is being widely used by the security industry, especially given any disadvantages that it may have. Is the anyway your chosen system can be improved? If so, can you suggest how? What do you think is needed to ensure that weapons and contraband are detected in the future?

Please note:

1. You should structure your report to include appropriate subheadings, including introduction and conclusion.
2. You are welcomed to include diagrams where they would help explain your point. Diagrams must be labelled, have a caption with a brief description of what it is and be referred to in the main text.
3. Extra reading and research on the subject are encouraged. Please consider the reliability of your sources when using them in your work.
4. Please reference your sources by using either one of the following reference styles:
    a. Harvard – example here: https://www.imperial.ac.uk/media/imperial-college/administration-and-support-services/library/public/harvard.pdf
    b. Numerical system - example here: https://www2.le.ac.uk/library/help/referencing/vancouver-numbered-system

Success Criteria:

- A scientific report is produced that has a clear structure, narrative.
- X-ray background (including evolution over time), their production, and how they are useful for the security industry is described.
- A clear indication of which of the two X-ray scanners is selected.
- Basic working principles of the selected X-rays scanner are described.
- A clear and evidence-backed argument (using referenced examples from literature) on the benefits, challenges and risks associated with a chosen X-ray scanner and X-ray technology itself. The argument is to cover different perspective views (i.e. airport, security, public).
- Evidence of analysis and critical thinking.
- Use of diagrams (clearly labelled, captioned and referred to in the text) to enrich the report and help deliver complex theory and ideas.
- Correct referencing style is used uniformly throughout the report.
- Using sources and references that did not come as part of the workbook.
- Correct use of subject-specific vocabulary.
- Clear and well-structured conclusion:
    - Conclusions that are clearly drawn from the evidence and discussions held in the main text.
    - Evidence of using resources outside those in the workbook to help support your narrative.
    - Independent and creative thinking, suggesting new ideas to help solve some of the challenges/risks identified in your report.

Understand (Subject Knowledge)	**Be able to do (Academic Skills)**
➢ How X-rays can be used to solve challenges posed by airport security. ➢ The science behind two most commonly used airport security scanners, their limitations and reasons for deployment. ➢ Using science to solve real-world problems is often an optimisation function. ➢ Ionising radiation and dose.	➢ Critically evaluate the chosen topic. ➢ Write a scientific report with the correct use of diagrams and references. ➢ Assess different viewpoints and establish a clear point of view. ➢ Use scientific evidence to help support your view/ overall narrative of your report. ➢ Use appropriate scientific language. ➢ Know how/why the Airport X-ray scanner works.

Notes

Tutorial 6 – Feedback tutorial

What is the Purpose of Tutorial 6?

- To receive feedback on your final assignment
- To respond to the feedback from your Uni Pathways teacher
- To write targets for improvement on your final assignment

Peer support and feedback:

One thing I liked is: …….

One thing that I have learned from others: ……

One thing that others have learned from me: ……...

One thing to improve is: ……

One idea I will borrow from others: …….

Self-reflection:

What were the most interesting discoveries that I have made whilst working on this project? About the topic? About myself? About the others?

What did I find the most useful? What made it so and how do I know that it was useful?

What got in the way of my progress and how can this be improved?

What could I do differently from a personal standpoint the next time I work with the same group or a different one?

Final assignment feedback from your Uni Pathways Teacher
(Remember to look at the mark scheme to help you understand what you have done well so far, and how you can do even better in your final assignment)

Here are three things that my Uni Pathways Teacher thought I did well in my draft assignment
•   •   •

Here are three things that my Uni Pathways Teacher thinks that I could do to get a higher mark in my final assignment
•   •   •

Tasks from my Uni Pathways Teacher to do during the feedback tutorial to help me improve
•   •   •
My response:

Actions I will take to improve my final assignment after this tutorial…
•   •   •

Hand in date for my final assignment:	

Tutorial 7 – Final tutorial

What is the Purpose of Tutorial 7?

- To receive feedback and a grade on your final assignment.
- To reflect on the programme including what you enjoyed and what was challenging.
- To ask any questions you may have about University.

Final assignment feedback from my Uni Pathways Teacher

Final mark:	University style grade:
Feedback: Here are three things that my Uni Pathways teacher thought I did well in my final assignment • • •	

Here are three things that my Uni Pathways teacher thinks I should remember for when I am doing this kind of study in the future
• • •

University

What questions do you still have about University after taking part in Uni Pathways?
•   •   •

Reflecting on Uni Pathways

What did you most enjoy about Uni Pathways?
•   •   •

What did you find challenging about the programme?	How did you overcome these challenges?
• • •	• • •

Appendix 1 – Referencing correctly

When you get to University, you will need to include references in the assignments that you write, so we would like you to start getting into the habit of referencing in your Brilliant Club assignment. This is important, because it will help you to avoid plagiarism. Plagiarism is when you take someone else's work or ideas and pass them off as your own. Whether plagiarism is deliberate or accidental, the consequences can be severe. In order to avoid losing marks in your final assignment, or even failing, you must be careful to reference your sources correctly.

What is a reference?
A reference is just a note in your assignment which says if you have referred to or been influenced by another source such as book, website or article. For example, if you use the internet to research a particular subject, and you want to include a specific piece of information from this website, you will need to reference it.

Why should I reference?
Referencing is important in your work for the following reasons:

- It gives credit to the authors of any sources you have referred to or been influenced by.
- It supports the arguments you make in your assignments.
- It demonstrates the variety of sources you have used.
- It helps to prevent you losing marks, or failing, due to plagiarism.

When should I use a reference?
You should use a reference when you:

- Quote directly from another source.
- Summarise or rephrase another piece of work.
- Include a specific statistic or fact from a source.

How do I reference?

There are a number of different ways of referencing, and these often vary depending on what subject you are studying. The most important to thing is to be consistent. This means that you need to stick to the same system throughout your whole assignment. Here is a basic system of referencing that you can use, which consists of the following two parts:

1. **A marker in your assignment**: After you have used a reference in your assignment (you have read something and included it in your work as a quote, or re-written it your own words) you should mark this is in your text with a number, e.g. [1]. The next time you use a reference you should use the next number, e.g. [2].
2. **Bibliography**: This is just a list of the references you have used in your assignment. In the bibliography, you list your references by the numbers you have used and include as much information as you have about the reference. The list below gives what should be included for different sources.

    a. **Websites** – Author (if possible), title of the web page, website address, [date you accessed it, in square brackets].

    E.g. Dan Snow, 'How did so many soldiers survive the trenches?', http://www.bbc.co.uk/guides/z3kgjxs#zg2dtfr [11 July 2014].

    b. **Books** – Author, date published, title of book (in italics), pages where the information came from.

    E.g. S. Dubner and S. Levitt, (2006) *Freakonomics*, 7-9.

    c. **Articles** – Author, 'title of the article' (with quotation marks), *where the article comes from* (newspaper, journal etc.), date of the article.

    E.g. Maev Kennedy, 'The lights to go out across the UK to mark First World War's centenary', Guardian, 10 July 2014.

Appendix 2

X-ray Security Imaging

Introduction

Ever since X-rays were discovered over a century ago, they have been a subject to constant innovation in the field of their generation, detection and data acquisition [21–23], resulting in a number of applications including medical imaging [24–27], non-destructive testing [28–30] and security screening [23,31–33].

The security industry takes a reactive stance rather than a proactive one currently [34,35]. Due to a number of hijackings that occurred during the 1970s and early 1980s, the primary concern of the security industry was focused on preventing weapons (i.e. metallic threat items such as guns and knives) from being taken on board aircraft [36,37]. As such, the main threat was not considered to be coming from improvised explosive devices (IEDs). A number of subsequent aircraft bombings including that of Pan Am flight 103 in 1988 over Lockerbie have shown that the *modus operandi* of the terrorists shifted towards the use and concealment of explosive devices aboard aircraft [36,38]. The Pan Am 103 disaster highlighted the inadequacy of airport scanners in detecting plastic explosives. This is because X-ray scanners of that time relied heavily on the principle that threat items would have a defined shape (i.e. knives and guns) and were primarily manufactured from metal [22,39]. Contrastingly, IEDs often incorporate commercial and military plastic explosives (i.e. PENT, RDX, TNT, Semtex) [36]. These have completely different characteristics, are soft and easily pliable into the desired shape (i.e. in the case of Pan Am 103, Semtex was placed inside a Toshiba cassette player with long delay timer [40]), having a similar X-ray profile to other harmless organic materials (i.e. marzipan [38]) [22,39,41]. Furthermore, only small amounts of high explosives (i.e. 250 grams) are required to achieve devastating results [42]. In 2001, the "shoe bomber" case shifted the attention of the security industry towards detection of peroxide based homemade explosives (HME) [43]. The threat of HME explosives does not come from their explosive power (i.e. inferior to that of commercial explosives) but from the fact that they are easy to initiate and synthesise in a clandestine environment [44]. The threat from HMEs was further reinforced after the 7 July 2005 London bombings, when four rucksacks containing 2-5 kg of home-made explosives were detonated at various locations around the city [45]. The transatlantic bomb plot of 2006 focused the attention of the security industry firmly

on the liquid HMEs [38]. Such devices could now be brought on board in parts (i.e. within everyday items such as drinks bottles, baby food, perfume) and reassembled on board an aircraft to prepare a highly explosive mixture [43,46,47]. During the 2010 bomb plot, a granulated pentaerythritol tetranitrate (PETN) explosive charge avoided detection by conventional security systems by being concealed in a printer cartridge (granulated to mimic toner density) and was only uncovered as a result of intelligence information [38,43,48]. The above incidents demonstrated that, in general, the primary threat to the airline industry has shifted from hijacking towards the use of explosive devices [38]. As a response, the focus of the security industry has now shifted toward the detection of plastic, liquid, amorphous and gel explosives, as well as home-made explosives as they are now one of the key weapons in the terrorist's arsenal.

With an annual growth of 3-5 % [38] in the aviation activity, the industry has focused on developing material specific screening techniques that complement conventional systems to enhance trace and bulk threat detection. To be widely adopted by the security industry, such techniques must be economically beneficial by providing high detection and low false alarm rates. False alarms are one of the major concerns of the security industry, costing an estimated 10 billion US dollars in the United States alone [43]. The higher the false alarm rate of a particular system, the more it is dependent on the human operator to resolve the problem, as such the whole process is time-consuming (i.e. an extra hour for security checks before departure) [22]. For newly developed systems to fit the security industry's needs (i.e. low turnover time & cost), they must have a high sensitivity (i.e. detect threat when present), specificity (i.e. detect no threat when none present) and high throughput (screen at < 5 sec. per bag) [38,41,43]. A straightforward way to improve the operator's performance is to employ systems that provide multiple discriminating features about the object in question [43]. There are some X-ray based screening techniques that fit this profile, and some of the most widely used include dual-energy, scatter based imaging and computer tomography (CT) [22].

In security screening, various techniques are being employed to inspect cargo, luggage and even passengers themselves if suspected of carrying illicit items on their person [49]. These techniques include manual searches of both passengers and baggage, use of sniffer dogs, trace explosive detection and X-ray inspection systems. As a result of an ever-growing number of flights that are taking off around the world on a daily basis (est. 49,000 flights per day [38]) and the fact that both US and EU regulatory authorities require 100 % screening of the hold baggage [40,50],

the security industry is faced with a number of operational challenges, and as such high sensitivity, specificity and throughput are required. On average there are around 10 million [22] pieces of luggage that are checked into large airports each year and as such searching them all by hand would be laborious and time-consuming (i.e. low throughput of a few tens of bags per hour [38]). This is especially after the fact that the average waiting time for passengers is already well above the established performance goal of 10 min [51]. In contrast, canines have relatively high sensitivity, specificity (i.e. low false alarm rates) are mobile and relatively inexpensive [52] making them a better-suited alternative. However, dogs are only fit to work for an hour before requiring a rest period, and their performance is heavily dependent on their training (i.e. can only alert to the presence of substance they've been trained on), as well the skills and enthusiasm of the dog handler in order to interpret response and motivate the dog [38,52] (presence of food may bias the response [53]). It is for this reason that both of these methods are not utilised as bulk detection methods, but instead as the second-level verifier, once the threat is established by the primary system [54]. Instead, X-ray imaging modalities are being implemented by the security industry, which on average, bring about two orders of magnitude increase in a number of bags being inspected per hour when compared to a hand search [54]. Amongst the most widely utilised in the industry is X-ray transmission imaging, dual energy imaging, computerised tomography (CT) and scatter based imaging (i.e. Coherent & Incoherent scatter), which are reviewed in the next sections.

Dual-energy X-ray Imaging

Conventional X-ray imaging system is one of the most widely known, legacy techniques available for the security industry [36]. This system utilises a broad beam X-ray source that is incident on the object in question and in its early stages, the sample dose (i.e. amount of X-rays attenuated by the object) was directly proportional to the viewing time (i.e. bags receiving a larger dose than needed) [22,36]. It operates on the principle that X-rays from the primary beam (i.e. fan beam) intercept the sample as it is passing through on the conveyor belt and are attenuated at different rates by various objects with the medium, as a direct result of the difference in their attenuation coefficient (μ/ρ) (see section **Error! Reference source not found.**). The resulting image (see Figure 15 (a)) consists of objects with varying degrees of grey contrast (the darker the shade of grey the more X-rays are attenuated) allowing the operator to distinguish between the various items such as guns, ammunition and knives, on the basis of their morphological features such as location, orientation, shape and size.

Figure 15 – X-ray image of a suitcase taken using the conventional (a) and dual-energy X-ray imaging approaches.

This system suffers from an inability to distinguish between a thin sheet of strong absorbing material (high atomic number) and a thick sheet of low absorbing material (low atomic number) [22,38]. Furthermore, it is highly dependent on the operator's experience (some can identify the make and model of the laptop purely based on its X-ray image) and ability to differentiate between objects in the radiographic image. It is further complicated by the fact that operator only has a limited time of 3-6 seconds [38] to decide if the threat is present. As such the operator may become complacent over time and have a higher miss rate as a result of low target prevalence effects (a shift in the decision-making process whereby the potential threats are missed as a result of conservative decisions) [23]. Threat image projection function (TIP) is where an image of a threat object is electronically projected within the X-ray image of the inspection volume and this has been introduced to the system as a direct response to reduce the prevalence effects and improve the operator's vigilance which is proven to decrease with time [23].

With the PanAm-103 disaster came the shift in threats from hijacking using weapons to smuggling of concealed IEDs on board aircraft [38]. Therefore, threat detection could no longer rely on discriminating between the high atomic number materials alone such as metals and instead required a system capable of differentiating between the low and high atomic number materials (i.e. organic and metals such as explosives and conventional weapons) [23,38]. Combined with the fact that operator's performance in distinguishing between threat objects within the X-ray image are significantly improved if colour [38] is applied helped dual-energy X-ray imaging (DEXI) system to become the mainstay screening tool for checkpoint security [33].

The DEXI system can be considered as an upgrade to a conventional transmission X-ray imaging and provides material discrimination capabilities on top of morphological features that are traditionally available within X-ray radiographs. This system operates on the principle that at high X-ray energies (i.e. $E_{High} \approx 160$ keV) and low energies (i.e. $E_{Low} \approx 80$ keV)

Compton and photoelectric effects respectively dominate. In this system, the Compton scattering cross section is energy dependent and increases with material density, while cross section associated with photoelectric effect is dependent on the atomic number of the material and energy (see sections **Error! Reference source not found.** & **Error! Reference source not found.**). Resulting in the simultaneous acquisition of two images produced by different energy levels from within the various energy windows. Figure 16 shows the dual-energy X-ray imaging system setup, with a sandwiched detector array that allows for separate acquisition of low and high-energy flux. However, other system configurations are possible, and these involve: varying the input energy of the X-ray source (i.e. true dual-energy) or using multiple sensors with different spectral responses (i.e. pseudo dual-energy) [22].

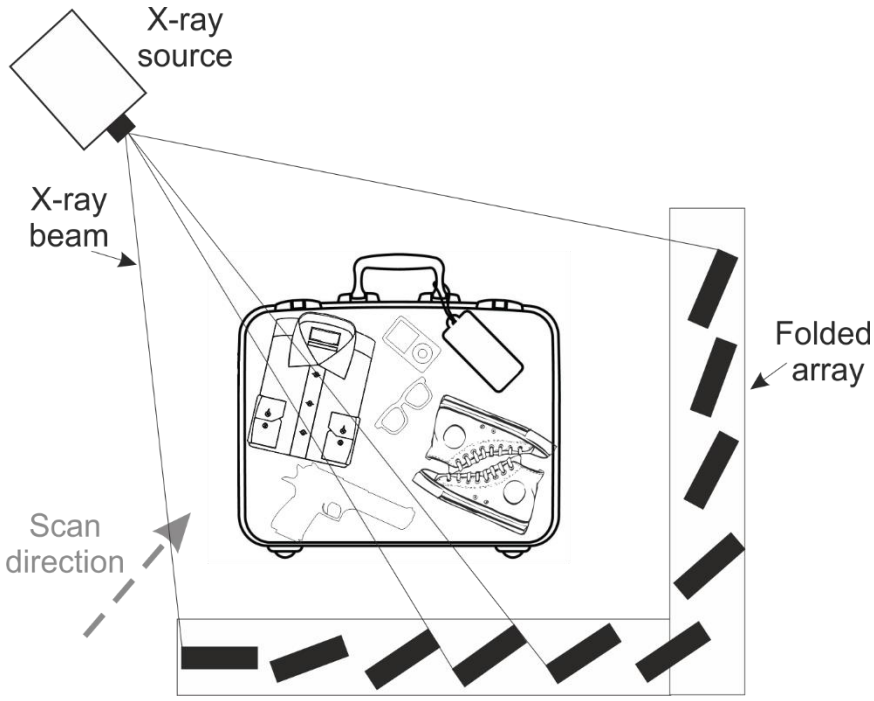


Figure 16 – Schematic diagram of the Dual-energy system setup. Here a polychromatic X-ray source interrogates the luggage; low energy transmission information is then detected by the low energy detector array and as it passes through the high-pass filter (i.e. copper) the low energy component is preferentially filtered off, and the high-energy signatures are then detected by the high-energy detector array. This sandwiched configuration can be easily used to convert conventional transmission systems [55] and is often employed in airports scanners [56].

Figure 16 shows the system in pseudo dual-energy configuration, and although it has been demonstrated that true dual-energy systems offer an improvement in discriminating power between materials (i.e. sensitivity), this is overcast by such systems' higher cost [21,22]. Dual-energy system allows for qualitative discrimination between the various materials on the basis of the difference in their attenuation at E_{High} and E_{Low} and for a calibrated system the

ratio between two energies can then be used to measure the effective atomic number [36] (atomic number of a hypothetical single element that gives the same X-ray attenuation as the material under evaluation [57]). The system then distinguishes between the various materials by assigning them into three groups with associated colours, as a function of their atomic number (see Figure 15 (b)) [56]. For instance, organic materials (i.e. $Z \leq 10$) are highlighted in orange, metallic (i.e. $Z \geq 20$) in blue and a mixture (i.e. $10 < Z < 20$) of the two materials in green on a pixel by pixel basis (see Figure 15 (b)) [36,55].

It is worth noting that dual-energy system resolves the fundamental problem that often present in conventional systems. That is that a thin high atomic number material will have the same attenuation as a thick low atomic number material. However, the multi-colored imagery produced by the DEXI system still suffer from poor conspicuity (i.e. how easy it is to find an object in the image via visual search [58]) brought about as a consequence of representing 3D objects in the 2D image (i.e. superimposition and occlusion). As a result, images tend to suffer from the following: lack of depth information for material in question, occlusion – whereby weak features of one object are masked by strong features of another (i.e. main reason behind the request for removal of large electrical items such as laptops from the passenger's luggage [59]) and density overlap between threat/non-threat objects (i.e. block of cheese and Semtex appearing near-identical in the X-ray image [31]) resulting in a false alarm rate of ≈ 20 % [22,38]. It has been shown that there is a correlation between the improvement in the operator's performance and the system that enables the user to manipulate the object's orientation and is capable of depth resolution (i.e. on a slice by slice basis to overcome superimposition) to produce less cluttered images [38,60]. As a result, several techniques have approached this problem by combining the dual-energy's material discriminating ability with volume imaging (i.e. CT [57,61]) and stereoscopic imaging (i.e. KDEX [62]) for instance. However, the sensitivity and specificity of such systems continue to suffer because dual-energy based systems are only capable of broad material characterisation into either organic or inorganic thus lacking the ability to specifically identify the material [22,41].

Computerised Tomography

Computer tomography has initially been developed to help aid the medical profession (with ≈ 80 million CT scans annually in USA [63]), providing excellent anatomical details and a 3D imaging system that helps to overcome the low conspicuity associated with conventional transmission X-ray imaging [58]. However, CT system's ability to provide 3D imaging that the operator can either pan around or view slice by slice have resulted that its uses have expanded beyond the medical imaging [64,65] to include security screening [22,23,38] and material science [66,67].

The fundamental difference between CT and other current X-ray security systems (section 0) comes from the fact that it allows for the item in question to be imaged in 3D. In a typical CT system, the sample is scanned using an X-ray source that rotates around a circular path using the doughnut-like structure referred to as gantry (see Figure 17 for typical 4th generation CT setup) [68,69].

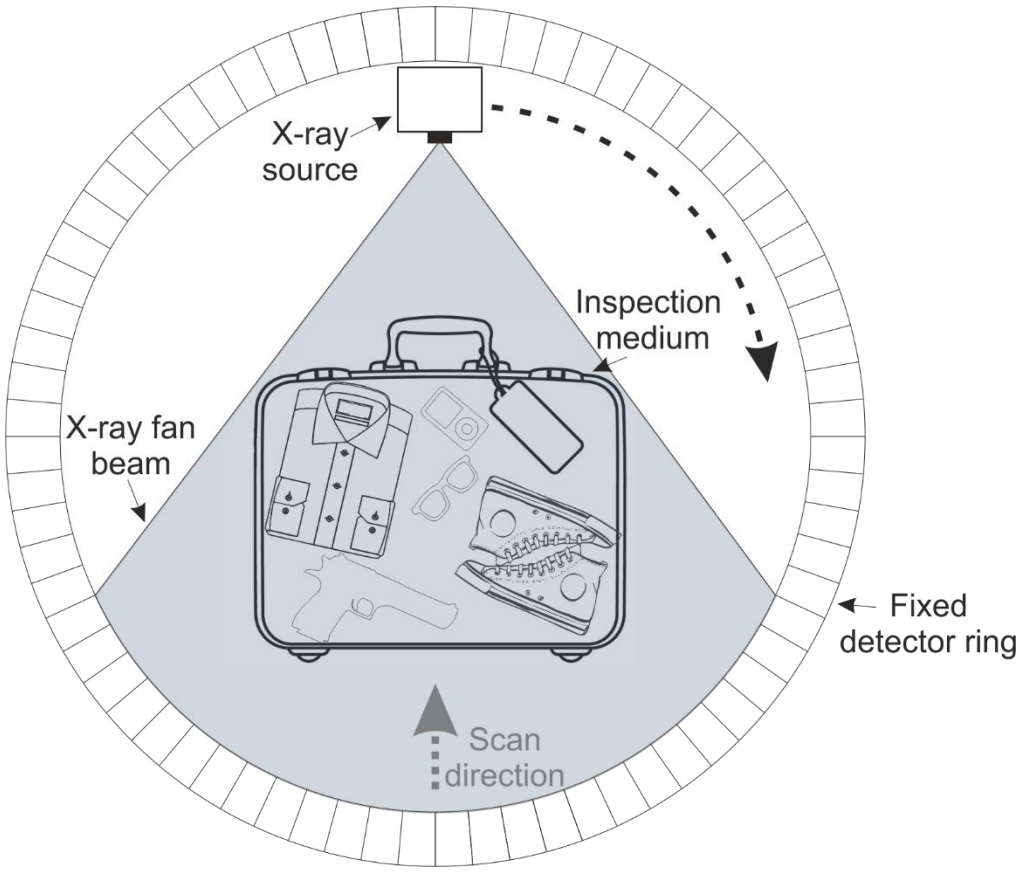


Figure 17 – Schematic diagram of conventional 4th generation CT [63,69]. This generation of CT consists of a gantry with rotating X-ray source producing a fan beam onto a stationary array of detectors that spans over 360° as the sample is moved through.

CT works on the principle that as the sample (patient) moves into the gantry; it is placed in the direct path of tightly collimated X-ray beams produced by a rotating X-Ray tube [68]. As the X-ray source moves along its circular path, the attenuation data is then recorded on detectors situated on the opposite side and each time it completes its full rotation; a 2D slice image is computed by using sophisticated mathematical techniques [70]. The sample then moves to the new position, and the process repeats, resulting in a series of 2D slice images that then can be used to generate 3D volumetric information about the sample, that includes inner or hidden objects (patient's anatomy) [68]. Giving the CT system the ability to mitigate against the fundamental shortcomings that are often associated with conventional 2D based screening systems (i.e. Dual-energy imaging, see section 0), namely superimposition and occlusion.

Since its initial introduction in the 1970s, the CT system has undergone substantial developments, driven by the medical industry's requirement for better spatial resolution and lower acquisition time. Scans performed within the patient's breath hold time allow for better quality scans because of a reduction in motion artefacts [58]. Table 1 shows the development of CT systems in succession (i.e. generations) and highlights the limitations that are associated with each iteration. A typical setup of 4th generation CT is shown in Figure 17 with rotate-stationary geometry being employed (i.e. fixed sample and detectors along the circumference of the gantry and a revolving wide fan X-ray source) [63]. In fourth-generation CT scanners, the spacing between the adjacent samples within a projection is primarily based on the sampling rate and not the detector cell size (i.e. 3rd gen. CT). Increasing the sampling rate can, therefore, help reduce the view aliasing artefacts (i.e. sharp stripes radiating from the edge of dense structures [71]) [69]. However, because each detector has to receive photons over a wide angle, effective use of post-sample collimation to remove the unwanted scatter is not possible. The system is further complicated by the need for >4800 detectors to surround the patient while maintaining an acceptable patient to source distance [69].

Table 1 – Historical overview of advances in CT development; highlighting the different setup configurations, associated scan times and limitations of each system (adapted from [58,63]).

Generation of CT	**Geometry**	**Scan time**	**Limitations**
1st	Translate-rotate geometry (i.e. X-ray source producing a narrow pencil beam is linked to the detector, linearly translated across the patient and rotated by 1° upon completion for a total of 180 views).	≈ 6 min	Slow and time consuming. Poor spatial resolution. Beam hardening artefacts (material appearing darker in the middle).
2nd	Translate-rotate geometry with narrow fan-beam and multiple detectors. Small angle between the narrow beams means that each detector can acquire separate views at different angles. Scan time is	≈ 20 s	The mechanical complexity associated with smooth and precise motion in the rotate-translate geometry hinder any further spatial resolution and scan time improvements.

	reduced as a function of 1/num. of detectors.		
3rd	Rotate-rotate geometry (X-ray fan beam is incident on the large detector array of the corresponding width; the X-ray tube and detector combination undergo the rotational motion together.	≈ 5 s	Detectors require recalibration before each scan. High-performance detectors needed to avoid ring artefacts. Spatial resolution limited by spacing between each sampling and by the size of each detector (i.e. tightly spaced measurements would require a variety of detectors).
4th	Rotate-stationary geometry (large detector ring with X-ray source rotating inside it). Later design saw X-ray source outside the ring with ring tilting out of the way as the X-ray beam is sweeping past.	≈ 5 s	With X-ray tube rotating inside large detector ring is required to keep patient dose acceptable = large number of detectors for good spatial resolution = expensive system. Scatter that causes image degradation was never resolved.
5th	Stationary-stationary geometry. No mechanical movement involved part of the gantry comprising of the X-ray source and the opposing side being the detectors.	≈ 50 ms	High cost. High noise and lower spatial resolution compared to conventional CT. Niche application market.
6th/7th	Spiral/helical CT geometry. The continuous volume of data is produced via simultaneous rotation of X-ray source and sample translation. Allows for improved contrast and reconstruction. Multiple, parallel rows of detectors are possible.	High-speed	High cost.

As mentioned earlier, one of the key advantages of the CT system is the fact that it gives the operator the ability to slice through the volume being interrogated and look at regions of interest. Significant improvements offered by such a setup are of little benefit in the cases of hand-luggage scanning, where low cost conventional approaches can be used to provide object discrimination and supplemented with hand search when required [23]. However, it has been shown that the operator's conspicuity (i.e. performance of detecting threat objects in an image) increases with the ability to obtain multiple views of the object and in the cases of hold luggage screening, which is often conducted remotely, the high cost of CT over the conventional dual-energy X-ray imaging can easily be justified [38,58]. The security industry sees the increased adoption of CT scanners with helical geometry because of their greater throughput and lower mechanical complexity [72]. The use of such a system enables the operator to have 360° field of view about the object [73]. Combining CT with dual-energy X-rays provides the operator with another layer of information and allows for a better discrimination between the threat and non-threat objects of the same density by different atomic numbers [72]. Dual-energy (see section 0) CT provides material discrimination in the form of pseudocoloured images that are based on the difference in photoelectric and Compton interactions at two distinct energies and the subsequently measured effective atomic numbers (atomic number estimate of a hypothetical single element that results in the same attenuation of X-rays as the compound/mixture being analysed [57]) of the materials. However, it is worth noting that the false alarm rate for CT system is relatively high at 30 % [50] which is well above the acceptable false alarm rate of 20 % [36].

In CT systems the filtered backprojection algorithm is used to reconstruct phantom images slice-by-slice, reduce tomographic blur and improve spatial resolution. However, the algorithm's performance is highly dependent on the number of views that are available from around the sample and their distribution. When the number of views is insufficient, this results in view aliasing artefacts (i.e. sharp stripes radiating from the edge of dense structures [71]) [63,74]. Furthermore, selection of filters during the reconstruction process results in a trade-off between the spatial resolution and image noise. For instance, a filter can be altered to give a sharper but noisier image, or a smoother but less noisy image; reduced noise is more important for imaging of low contrast within soft tissue [58,63].

When considered in a security setting, CT requires a high signal to noise ratio to produce images that are suitable for reconstruction and needs a high-energy X-ray source that is capable of penetrating through the medium under the interrogation [22]. However, high-energy X-ray sources have extended focal spot sizes and as such deteriorate the spatial resolution of the system [63]. The system requires a complex, bulky setup to accommodate all the moving and stationary components, necessary radiation shielding, resulting in a system that weighs more than one hundred kilogrammes [75]. Kinetic depth effect X-ray imaging (KDEX) has been developed as an alternative technique, and it offers some key

advantages. First of all, whereas CT requires a minimum of 100 views [22] to reconstruct the object in 3D, KDEX requires only 15 perspective views [75]. This reduces the data acquisition time without suffering from tomographic blur [28] that is often associated with CT reconstructions [22]. Secondly, it has been estimated that initial purchase and subsequent running costs of KDEX systems are an order of magnitude lower compared to its CT counterpart [75]. KDEX allows the visualisation of the inspection volume in 3D by utilising an X-ray source with a fan beam, and an array of line detectors positioned at a regular angular separation from one another (e.g. 15° [76]). The conveyor belt, moving at a constant speed, transports the object in question through the fan beam and a set of images at slightly different perspectives are obtained [62]. This set of images is then played in sequence, giving the operator the ability to look around the object (i.e. the object appears to rotate), with parallax (i.e. depth perception) being obtained as a result of differences in angular velocity of individual object with the inspection medium (i.e. objects closer to the source rotate faster than the objects further away) [62,76]. It is worth noting that contrary to its stereoscopic counterpart where diplopia is achieved at relatively low separation angles; KDEX can afford much larger angular separation (i.e. ±15° [76]), as defined by Panum's fusional area (i.e. range over which two images can be fused into one) [77,78]. Meaning that KDEX allows for a much better axial resolution along the z-axis (i.e. the separation between adjacent axial focal plane positions) to be achieved. KDEX can also be operated in dual-energy mode (for dual-energy systems see section 0) to achieve basic material discrimination between organic and inorganic materials [62]. This material discriminating ability of KDEX has been further enhanced by combining it with a scatter based technique, namely X-ray diffraction (for a more detailed review of this technique see section **Error! Reference source not found.**), which provides a highly specific patterns of substances in the inspection volume, which are then compared against the database of known materials [76].

CT systems, on the other hand, suffer from problems associated with resolving and detecting explosives in sheet form. Because flat samples (i.e. sheet explosives, paintings and printed circuit boards) vary significantly in one dimension compared to the other two, this results in the large variation of transmitted X-rays as the sample is rotated along the axis perpendicular to the X-ray beam [74,79]. Meaning that for some angles during the sample rotation there can be no transmission or limited X-ray transmission resulting in artefacts (i.e. streak patterns [80]) and noise within the reconstructed image. One way of overcoming this problem is to skip the projections with high X-ray absorptions, which can be achieved with the aid of limited angle tomography [79]. Limited angle tomography is widely referred to as digital tomosynthesis and is regarded as a new field in medical, industrial and security imaging [81]. Digital tomosynthesis produces a set of slice images from a series of projection images obtained via X-ray source motion over the defined path [80].

When used in the security setting, dual-energy CT system's lack of material specificity applies to objects with similar absorption coefficients being assigned the same colour (i.e. cheese and plastic explosives) [31], something that has been addressed with X-ray diffraction.

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