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| **Lesson Number: 26.1** |
| **Lesson Title: The discovery of the nucleus** |
| **Specification Reference** | **3.8.1.1** |
| **Learning Objectives** |
| Qualitative study of Rutherford scattering.Appreciation of how knowledge and understanding of the structure of the nucleus has changed over time. |
| **Opportunities for Assessment** |
| Questions on page 440 |
| **Starter:** | Slide #1 is an introduction to this topic and also can create a thought provoking discussion on what flaws our current model of the atom might have. Note that Rutherford’s model predated quantum mechanics and couldn’t answer questions like “Why are the electrons in shells?” |
| **Main:** | Slides #1 and #2 quickly introduce J.J.Thomson and E.Rutherford – A good research homeworkSlides #4 and #5 go through the experiment that Rutherford performed and why the result was a surpriseSlide #6 links the results to the model and how Rutherford came up with this new way of thinking – Note that it is critical for new models to explain the data and to fit in with the rest of science theorySlide #7 introduces the idea of estimating the size of the atomic nucleus |
| **Plenary:** | Slide #8 is a summary |

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| **Homework:** | Question on page 440, research the life and discoveries of Ernest Rutherford or J.J.Thomson |
| **Differentiation / Extension / S&C** |
| Give the results of Rutherford’s experiment and get pupils to come up with a model of their own – how can this model be used to find the size of an atom / nucleus? |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| General idea of statistics and frequency | Ernest Rutherford (Page 438) research |
| **RESOURCES:** |
| None |
| **Risk Assessment** e.g. CLEAPSS card reference |
| None |
| **Working Scientifically (HSW)** |
| N/A |

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| **Lesson Number: 26.2** |
| **Lesson Title: The properties of α, β, and γ radiation** |
| **Specification Reference** | **3.8.1.2** |
| **Learning Objectives** |
| Their properties and experimental identification using simple absorption experiments; applications e.g. to relative hazards of exposure to humans.Applications also include thickness measurements of aluminium foil paper and steel. |
| **Opportunities for Assessment** |
| Question on page 445 |
| **Starter:** | Slides #1 to #3 introduce the lesson and two of the famous scientists that have worked on radiation – a good research topic for homework |
| **Main:** | Slide #4 recaps the absorption of radiation from GCSE and extends the knowledge slightly on absorption – discussion of the uses of absorption to monitor paper aluminium thickness is appropriate hereSlides #5 to #7 explain moving charges in magnetic fields – how much depth to go into here depends on whether the students have studied lessons 24.2 and 24.3Slide #8 is a quick recap of deflection in an electric field from GCSE |
| **Plenary:** | Slide #9 is a summary |

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| **Homework:** | Questions on page 445, Research the life and discoveries of Marie Curie |
| **Differentiation / Extension / S&C** |
| Go into more depth on the circular orbits of particles, why they spiral in a magnetic field, ranges of alpha and beta, discovery of the neutrino due to beta have a range of velocities |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| N/A | Marie Curie and her discoveries, women in science |
| **RESOURCES:** |
| Demonstration:* Alpha, Beta and Gamma sources
* Geiger tube radiation detection / counting kit
* Card, Aluminium and Lead of various thicknesses
 |
| **Risk Assessment** e.g. CLEAPSS card reference |
| Radiation hazard risk assessment:* Follow in-house protocols on use and management of sources including:
	+ Do not point sources at people
	+ use at maximum distance (use forceps), and away from students
	+ Use for least amount of time possible
	+ Ensure all sources are counted in and out
	+ Do not leave sources unattended
 |
| **Working Scientifically (HSW)** |
| N/A |

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| **Lesson Number: 26.3** |
| **Lesson Title: More about α, β and γ radiation** |
| **Specification Reference** | **3.8.1.2** |
| **Learning Objectives** |
| Inverse-square law for γ radiation:  |
| **Opportunities for Assessment** |
| Questions on page 448 |
| **Starter:** | Slide #1 enables a quick recap of the three main ionisation types and their properties |
| **Main:** | Slides #2 - #4 go through and recap GCSE knowledge of what each of the types of radiation are and what they are made fromSlides #5 and #6 explain and derive the inverse square law for gamma – This knowledge is critical as it forms the work for the required practical #12 next lessonSlides #7 - #10 handle the nuclear equations of alpha, beta, positron and electron capture respectively |
| **Plenary:** | Slides #11 and #12 form a summary |
| **Homework:** | Questions on page 448, plan gamma radiation experiment (practical #12) |
| **Differentiation / Extension / S&C** |
| Expand on the inverse square law to astrophysics and distance determination from magnitude and luminosity of stars |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| Use of nuclear equations | N/A |
| **RESOURCES:** |
| None |
| **Risk Assessment** e.g. CLEAPSS card reference |
| None |
| **Working Scientifically (HSW)** |
| N/A |

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| **Lesson Number: 26.3a** |
| **Lesson Title: Investigation of the inverse-square law for gamma radiation** |
| **Specification Reference** | **3.8.1.2** |
| **Learning Objectives** |
| Inverse-square law for γ radiation: Experimental verification of inverse-square law. |
| **Opportunities for Assessment** |
| Assessing the practical aspect of the lesson**Skills Assessment (Required practical 12)**AT (a),(b),(k),(l) |
| **Starter:** | Recap gamma radiation and the inverse square law from last lesson (Slides #1 and #2) |
| **Main:** | Slide #3 explains to students that their teacher will decide how much dependence they are given in this experiment. See pages 110-111 of the AQA practical handbook for Physics for full detailsSlide #4 outlines the assessed skills that will be looked at by the teacher. Students should keep these in mind and ensure that their teacher watches them perform these skills during the practical.Depending on the outcomes that the teacher wishes to assess, the pupils can either be given a method to follow or a lesson can be used as a full research and planning sessionThe experiment needs to be performed. See pages 110-114 of the practical handbook for A-Level Physics for full details. |
| **Plenary:** | Go over the experiment and the results; write up the experiment in full; discuss the assessing of the skills and the outcome assessed by the teacher. |
| **RESOURCES:** |
| Groups:* gamma source (e.g. 185 kBq (5 µCi) Cobalt 60 ‘closed’ source)
* source holder or retort stand, boss and clamp
* scaler with integral power supply for GM tube
* geiger muller tube suitable for gamma detection
* metre ruler
* stopclock
 |
| **Risk Assessment** e.g. CLEAPSS card reference |
| Radiation hazard risk assessment:* Follow in-house protocols on use and management of sources including:
	+ Do not point sources at people
	+ use at maximum distance (use forceps), and away from any students
	+ Use for least amount of time possible
	+ Ensure all sources are counted in and out
	+ Do not leave sources unattended
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| **Lesson Number: 26.4** |
| **Lesson Title: Dangers of radioactivity** |
| **Specification Reference** | **3.8.1.2** |
| **Learning Objectives** |
| Applications e.g. to safe handling of radioactive sources.Background radiation; examples of its origins and experimental elimination from calculations. |
| **Opportunities for Assessment** |
| Question on page 451 |
| **Starter:** | Slide #1 poses some questions to start a discussion on radiation and safety |
| **Main:** | Slide #2 recaps the main ionising radiation, the list may contain a few new ones the students don’t think ofSlide #3 links back to radiation safety and how we monitor dosage in workers in the UKSlide #4 explains the difficulty in using simple units for dosage when different types of radiation have different outcomes – Sieverts must be known but calculations are not neededSlide #5 is a simple pie chart of approximate background radiations. This is from the included excel sheet which can be used as a homework to research the actual values in your areaSlide #6 explains how radioactive materials are stored – There is remarkably little created in the UK; a power station can have a fuel rod that lasts up to 20 years!Slide #7 is a good opportunity to go over the risk assessments from the practical work (#12) on gamma radiation |
| **Plenary:** | Slide #8 is a summary |

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| **Homework:** | Question on page 451, research the dosage limits for workers, public and nuclear workers in the UK |
| **Differentiation / Extension / S&C** |
| Create a talk on nuclear safety in the UK quoting facts and figures from HSE |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| N/A | Is there such a thing as a *safe* radiation limit? |
| **RESOURCES:** |
| None |
| **Risk Assessment** e.g. CLEAPSS card reference |
| None |
| **Working Scientifically (HSW)** |
| Radiation does limits, page 450 |

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| **Lesson Number: 26.5** |
| **Lesson Title: Radioactive Decay** |
| **Specification Reference** | **3.8.1.3** |
| **Learning Objectives** |
| Random nature of radioactive decayQuestions may also involve use of molar mass or the Avogadro constantApplications e.g. relevance to storage of radioactive waste, radioactive dating etc. |
| **Opportunities for Assessment** |
| Questions page 454 |
| **Starter:** | Slide #1can start a discussion on statistics – alternatively begin with Einstein’s famous quote “He [God] does not play dice” |
| **Main:** | Slides #2 and #3 recap GCSE half-life understandingSlide #4 recaps GCSE work on the Avogadro constant – pupils often need to completely rework this! Note that the Avogadro constant can be found by taking 12g and dividing it by 12x*u* where *u* is the subatomic mass unit; this can help pupils understand it’s meaningSlide #5 extends the half-life understanding to activity – Research on Becquerel and his work could form a homeworkSlide #6 links activity to power and gives an example of weighing up the variables in the selection of isotopes for jobs – Pupils seldom realise that many nuclear waste isotopes have relatively short half-lives, or that the fuel rods in nuclear power stations can last between 12 and 20 years |
| **Plenary:** | Slide #7 is a summary |
| **Homework:** | Questions page 454, investigate half-life of water draining from an open bottle with a hole in the bottom |
| **Differentiation / Extension / S&C** |
| Research the power units in long distance space probes |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| Exponential decay | N/A |
| **RESOURCES:** |
| Optional:* Dice or coloured discs to perform a half-life experiment
 |
| **Risk Assessment** e.g. CLEAPSS card reference |
| None |
| **Working Scientifically (HSW)** |
| N/A |

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| **Lesson Number: 26.6** |
| **Lesson Title: The theory of radioactive decay** |
| **Specification Reference** | **3.8.1.3** |
| **Learning Objectives** |
| Random nature of radioactive decay; constant decay probability of a given nucleus;Use of activity, Modelling with constant decay probability.Questions may be set which require students to useHalf-life equation: *T*½ Determination of half-life from graphical decay data including decay curves and log graphs. |
| **Opportunities for Assessment** |
| Questions page 457 |
| **Starter:** | Slide #1 enables pupils to discuss quantum mechanics and the uncertainty inherent in this field of Physics – try to remove the preconception that this is due to a lack of knowledge but instead it is simply how the universe works! |
| **Main:** | Slide #2 links activity to rate of change of particles and hence the decay constantSlides #3 to #6 are a recap of exponential decay mathematics and use differentiation to derive the exponential decay formula – Whilst no needed for A-Level Physics this is included again as an essential understanding to why the formula has to have *e* in itSlide #7 moves on from the derivation of the exponential formula to putting it in context with activity – It is worth showing that this formula works with *N* or *C*Slide #8 is the essential skill of graphically finding the half-life of a sample and reducing uncertainty in the exercise.Slide #9 is a derivation of the link between activity and half-life – The derivation need not be understood but ensure all pupils can find ln2 on a calculator |
| **Plenary:** | Slide #10 is summary |

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| **Homework:** | Questions page 457; Research Euler’s constant (ln2) |
| **Differentiation / Extension / S&C** |
| Get the pupils to work one step ahead of the mathematical derivation slides, using them as assistance and clarification instead of a teaching aid |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| Exponential decay and differentiation, natural logs | N/A |
| **RESOURCES:** |
| None |
| **Risk Assessment** e.g. CLEAPSS card reference |
| None |
| **Working Scientifically (HSW)** |
| N/A |

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| **Lesson Number: 26.7** |
| **Lesson Title: Radioactive isotopes in use** |
| **Specification Reference** | **3.8.1.2, 3.8.1.3** |
| **Learning Objectives** |
| Appreciation of balance between risk and benefits in the uses of radiation in medicine.Applications e.g. relevance to storage of radioactive waste, radioactive dating etc. |
| **Opportunities for Assessment** |
| Questions page 461 |
| **Starter:** | Slide #1 enables a discussion of the pros and cons of radioactive sources and nuclear material in general |
| **Main:** | Slide #2 shows the essential decisions that must be made and considerations needed in the selection of an isotope – It is useful if pupils write this list down and then discuss each point on it for each of the examples given in the coming slidesSlides #3 - #7 are the main uses of radioactive material, with the exception of nuclear fission and weapons as these are best discussed in the lessons on fission and fusion – Discuss each use in detail and link to slide #2A nice activity here is to allocate a slide to each group and have them do research on the isotopes used and link them to the bullet points in slide #2, feeding back to the class their findings as presentations |
| **Plenary:** | Slide #8 is a summary although feedback from students can perform the same task |
| **Homework:** | Questions page 461, researching uses and selection of isotopes |
| **Differentiation / Extension / S&C** |
| Looking deeper into why certain isotopes are used; research the meta-stable state of technetium |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| N/A | Use of radiation – balancing good against badIs science intrinsically good or bad or just the people who use it? |
| **RESOURCES:** |
| Computer room (Optional) |
| **Risk Assessment** e.g. CLEAPSS card reference |
| None |
| **Working Scientifically (HSW)** |
| N/A |

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| **Lesson Number: 26.8** |
| **Lesson Title: More about decay modes** |
| **Specification Reference** | **3.8.1.4** |
| **Learning Objectives** |
| Graph of *N* against *Z* for stable nuclei.Possible decay modes of unstable nuclei including α, β+, β− and electron capture.Changes in *N* and *Z* caused by radioactive decay and representation in simple decay equations.Questions may use nuclear energy level diagrams.Existence of nuclear excited states; γ ray emission; application e.g. use of technetium-99m as a γ source in medical diagnosis. |
| **Opportunities for Assessment** |
| Questions page 464 |
| **Starter:** | Slide #1 enables a discussion about what causes radioactive decay and what controls which type occurs – Ask “Why do they decay” or “What keeps a nucleus together” |
| **Main:** | Slide #2 is a description of the standard *N/Z* type graph and how to interpret an isotopes position on it – Shading regions as Beta plus, Beta minus helps students interpret this betterSlide #3 is an optional recap of Year 1 particles and forcesSlides #4 and #5 simply describe the *N/Z* relationship for isotopes up to and beyond 20Slide #6 reaffirms the selections rules from slide #2 – an possible activity is to have pupils draw out a graph using every 5th element in the periodic table then plot on isotopes and derive what their decay modes areSlide #7 shows more complex decay chains or series – If pupils have graphed an *N/Z* then it is interesting to plot this onto itSlide #8 explains the metastable state of technetium – This links nicely with lesson 26.7 and why it is safe to use as a medical tracer |
| **Plenary:** | Slide #9 is a summary |

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| **Homework:** | Questions page 464 |
| **Differentiation / Extension / S&C** |
| Decay chains and selection rules in detail – link to nuclear fission; research of metastable states |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| Use of graphs and axis | N/A |
| **RESOURCES:** |
| None |
| **Risk Assessment** e.g. CLEAPSS card reference |
| None |
| **Working Scientifically (HSW)** |
| Examples of diagnostic uses of Technetium, page 465 |

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| **Lesson Number: 26.9** |
| **Lesson Title: Nuclear Radius** |
| **Specification Reference** | **3.8.1.5** |
| **Learning Objectives** |
| Estimate of radius from closest approach of alpha particles and determination of radius from electron diffraction.Knowledge of typical values for nuclear radius.Students will need to be familiar with the Coulomb equation for the closest approach estimate.Dependence of radius on nucleon number:  derived from experimental data.Interpretation of equation as evidence for constant density of nuclear material.Calculation of nuclear density.Students should be familiar with the graph of intensity against angle for electron diffraction by a nucleus. |
| **Opportunities for Assessment** |
| Question page 467 |
| **Starter:** | Slide #1 introduces the topic and is an interesting discussion point – can we “see” individual atoms? What are their sizes compared to the wavelength of visible light? |
| **Main:** | Slide #2 explains how Coulomb’s law can be used to estimate the diameter of a nucleusSlides #3 - #4 link back to the work in Year 1 on diffraction and de Broglie waves and some time should be spent recapping these topics.Slide #5 simply states the formula to use for calculating radius from nuclear angle; a full derivation of this is given in the course book on page 467 – The use of a computer room and spreadsheet here can make an interesting lesson for pupils to explore this relationshipSlide #6 explains atomic density and why it is a constant for all atoms; links nicely to astrophysics and a common calculation to show the human race can fit within a sugar cube |
| **Plenary:** | Slide #7 is a summary |

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| **Homework:** | Question page 467; research Neutron stars |
| **Differentiation / Extension / S&C** |
| Use of spreadsheet to find the correlation between nuclear number and nuclear radius |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| Formula use and derivation | N/A |
| **RESOURCES:** |
| Optional – Computer room |
| **Risk Assessment** e.g. CLEAPSS card reference |
| None |
| **Working Scientifically (HSW)** |
| N/A |

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| **Lesson Number: 27.1** |
| **Lesson Title: Energy and Mass** |
| **Specification Reference** | **3.8.1.6** |
| **Learning Objectives** |
| Appreciation that applies to all energy changesSimple calculations involving mass difference and binding energy. |
| **Opportunities for Assessment** |
| Questions page 474 |
| **Starter:** | Slide #1 is a thought provoking question – can students describe what mass and energy actually are? (Harder than it sounds) |
| **Main:** | Slide #2 introduces Albert Einstein and his most famous works – This can form differentiated homework ranging from a simply Biography to research on relativitySlide #3 shows how profound Einstein’s formula actually is… another analogy is a spring gets more massive when it is pulled or pushed from its resting positionSlides #4 - #7 go through several sub-atomic particle interactions and the associated energy changes that occurSlide #8 links the work done to the strong force – Realisation that the strong force holding two nucleons together is about 200N is quite astonishing to most students |
| **Plenary:** | Slide #9 is a summary |

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| **Homework:** | Questions page 474; research Albert Einstein |
| **Differentiation / Extension / S&C** |
| Links back to fundamental forces and Year 1 particle physics; research relativity |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| Mass / Energy formula | Understanding concepts of things we cannot see |
| **RESOURCES:** |
| None |
| **Risk Assessment** e.g. CLEAPSS card reference |
| None |
| **Working Scientifically (HSW)** |
| N/A |

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| **Lesson Number: 27.2** |
| **Lesson Title: Binding energy** |
| **Specification Reference** | **3.8.1.6** |
| **Learning Objectives** |
| Appreciation that applies to all energy changes,Simple calculations involving mass difference and binding energy.Atomic mass unit, uConversion of units; 1 u = 931.5 MeVGraph of average binding energy per nucleon against nucleon number.Students may be expected to identify, on the plot, the regions where nuclei will release energy when undergoing fission/fusion |
| **Opportunities for Assessment** |
| Questions page 477 |
| **Starter:** | Slide #1 is looking to see if students can come up with the idea of binding energy by themselves |
| **Main:** | Slide #2 outlines another profound idea that 1+1+1≠3 when putting sub-atomic particles togetherSlide #3 shows how mass deficit can be calculatedSlide #4 shows the mass spectrometer that students should be familiar with – an extension exercise can be to calculate m/q for several isotopesSlide #5 defines the atomic mass unit – A common question as to why C12 was used is because using Hydrogen is difficult due to the problems separating it from its isotope deuteriumSlide #6 introduces binding energy and stability – A common mistake for students is to forget that this is binding energy **per nucleon** and they don’t divide by the nucleon number |
| **Plenary:** | Slide #7 is a summary |

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| **Homework:** | Questions page 477; research binding energy and link to star life cycles |
| **Differentiation / Extension / S&C** |
| Quantum tunnelling discussion and quantum effects |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| Use of Einstein’s formula and application to binding energyConversion of units to MeV | N/A |
| **RESOURCES:** |
| None |
| **Risk Assessment** e.g. CLEAPSS card reference |
| None |
| **Working Scientifically (HSW)** |
| α particle tunnelling, page 476 |

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| **Lesson Number: 27.3** |
| **Lesson Title: Fission and fusion** |
| **Specification Reference** | **3.8.1.7, 3.8.1.8** |
| **Learning Objectives** |
| Appreciation that  applies to all energy changes,Simple calculations involving mass difference and binding energyFission and fusion processesSimple calculations from nuclear masses of energy released in fission and fusion reactionsAppreciation that knowledge of the physics of nuclear energy allows society to use science to inform decision making |
| **Opportunities for Assessment** |
| Questions page 480 |
| **Starter:** | Slide #1 is an introduction to fusion power and links back to GCSE work that students have done – Next lesson the reactor is discussed in detail so this is only a memory-jogging exercise |
| **Main:** | Slide #2 shows a fission reaction – Note that the daughter nuclei are not set and various are created which then follow decay chainsSlide #3 explains the induced fission reaction – interestingly this is another example of discoveries being made by accident; neutron bombardment experiments were being done to increase atomic number and to try and find new isotope when two were found to split unexpectedlySlide #4 graphically shows the idea of a chain reaction – link this to possible disasters if not controlled and nuclear bombsSlides #5 - #6 shows the p-p chain which is the main fusion occurring in main sequence starsSlide #7 - #8 explains mass loss and gives a simple problem for pupils to solveSlides #9 - #11 go into a little detail about fusion reacts performed on Earth and the moral choices we as humans need to make – Homework ideas can be to research the current fusion experiments being performed, the new plant being built in France or possibly the moral implications of fission power |
| **Plenary:** | Slide #12 is a summary |

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| **Homework:** | Questions page 480; research fusion plants; create a discussion / presentation on the dangers of nuclear power |
| **Differentiation / Extension / S&C** |
| Research in detail the current understanding of fusion using more complex ideas e.g. lasers to push the particles together |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| Use of  | Nuclear power – a moral argument |
| **RESOURCES:** |
| None |
| **Risk Assessment** e.g. CLEAPSS card reference |
| None |
| **Working Scientifically (HSW)** |
| N/A |

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| **Lesson Number: 27.4** |
| **Lesson Title: The thermal nuclear reactor** |
| **Specification Reference** | **3.8.1.7, 3.8.1.8** |
| **Learning Objectives** |
| Fission induced by thermal neutrons; possibility of a chain reaction; critical mass.The functions of the moderator, control rods, and coolant in a thermal nuclear reactor.Details of particular reactors are not required.Students should have studied a simple mechanical model of moderation by elastic collisions.Factors affecting the choice of materials for the moderator, control rods and coolant. Examples of materials used for these functions.Fuel used, remote handling of fuel, shielding, emergency shut-downProduction, remote handling, and storage of radioactive waste materialsAppreciation of balance between risk and benefits in the development of nuclear power |
| **Opportunities for Assessment** |
| Questions page 482 |
| **Starter:** | Slide #1 is an introduction to nuclear power – Do pupils know where the nearest plant to them is? |
| **Main:** | Slide #2 lists the key points and parts in a reactor and this should explainedSlide #3 is a drawing of the inside of a gas cooled plant, link slide #2 parts to thisSlides#4 and #5 cover the learning objectives associated with understanding the choices of the main materials in the construction of a power plant and the safety considerationsSlide #6 explains critical massSlides #7 and #8 go over the different aspects of waste management – All of the high level waste produced in the UK from nuclear power over 50 years will fill a single double decker bus |
| **Plenary:** | Slide #9 is a summary |

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| **Homework:** | Questions page 482, research nuclear disasters and their causes |
| **Differentiation / Extension / S&C** |
| Write a moral based literature review of the disasters that have occurring in nuclear installations |
| **Numeracy / Literacy** | **SMSC / Fundamental British Values** |
| N/A | Nuclear power and accidentsAmount of nuclear waste (All of the UK waste fits inside a single bus, from 50 years of use) |
| **RESOURCES:** |
| None |
| **Risk Assessment** e.g. CLEAPSS card reference |
| None |
| **Working Scientifically (HSW)** |
| A nuclear future page 483 |

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Slides #1, #3 and #5 – Wikipedia (Public Domain)