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| Year 12 Physics |
| Depth Study guide |
| IntroductionWe recommend that an ANSTO excursion becomes the starting point for a nuclear science depth study. ANSTO’s Year 12 Physics excursion, together with the *ANSTO* *Year 12 Physics Excursion Workbook*, helps students cover content selected from Module 8: From the Universe to the Atom – Properties of the Nucleus and Working Scientifically.Our ANSTO Year 12 Physics Depth Study Guide provides students and teachers with ideas and resources for depth study activities following their excursion.  |
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Year 12 Physics Nuclear Science Depth Study

An ANSTO excursion can be the ideal start for a nuclear science depth study. Students will cover the following syllabus content:

**Module 8: From the Universe to the Atom**

**Properties of the nucleus**

Students:

* analyse the spontaneous decay of unstable nuclei, and the properties of the alpha, beta and gamma radiation emitted (ACSPH028, ACSPH030)
* examine the model of half-life in radioactive decay and make quantitative predictions about the activity or amount of a radioactive sample using the following relationships:

Nt = N0e-λt

 λ = ln(2)/t1/2

where Nt = number of particles at time t, N0 = number of particles present at t = 0, λ = decay constant, t1/2 = time for half the radioactive amount to decay.

* model and explain the process of nuclear fission, including the concepts of controlled and uncontrolled chain reactions, and account for the release of energy in the process
* analyse relationships that represent conservation of mass-energy in spontaneous and artificial nuclear transmutations, including alpha decay, beta decay, nuclear fission and nuclear fusion
* account for the release of energy in the process of nuclear fusion
* predict quantitatively the energy released in nuclear decays or transmutations, including nuclear fission and nuclear fusion, by applying:

– the law of conservation of energy

– mass defect

– binding energy

– Einstein’s mass–energy equivalence relationship 𝐸 = 𝑚𝑐2

**Deep Inside the atom**

Students:

* investigate the operation and role of particle accelerators in obtaining evidence that tests and/or validates aspects of theories, including the Standard Model of matter

**Working Scientifically**

* Questioning and predicting
* Planning investigations
* Conducting investigations

We recommend students use our *Year 12 Physics Depth Study Guide* for ideas and resources for depth study activities after their excursion.

## NESA requirements for Depth Studies

* A minimum of 15 hours of in-class time is allocated in both Year 11 and Year 12
* At least one depth study must be included in both Year 11 and Year 12
* The two Working Scientifically outcomes of Questioning and Predicting, and Communicating must be addressed in both Year 11 and Year 12
* A minimum of two additional Working Scientifically skills outcomes, and further development of at least one Knowledge and Understanding outcome, are to be addressed in all depth studies.

## Topic 1: Structure of matter, atomic theory and nuclear radiation

### Suggested activities

* ANSTO scientists analyse the composition of gases trapped inside deep Antarctic ice to determine historical changes in our climate and atmosphere. Carbon-14, beryllium-10 and chlorine-36 are used routinely to determine the age of these ice core samples.

Carbon-14 half-life: 5730 years

Beryllium-10 half-life: 1,390,000 years

Chlorine-36 half-life: 301,000 years

Nt = N0e-λt

λ = $\frac{ln2}{t1/2 }$

where Nt = number of particles at time *t*, N0 = number of particles present at *t = 0*, λ = decay constant, t1/2 = time for half the radioactive amount to decay.

Use the data and equations above to:

1. Calculate the decay constant for each isotope
2. Plot the decay curve for each isotope
3. Estimate the proportion of each isotope remaining in a sample of Antarctic ice 45,000 years old
* Alpha, beta and gamma radiation may be emitted when unstable nuclei decay. Radioisotopes are used for specific medical, industrial and agricultural purposes based on the properties of the radiation they emit.
1. Choose one example each of an alpha emitter, a beta emitter and a gamma emitter. Explain how the properties of the radiation emitted by the chosen isotope makes it suitable for an identified purpose in medicine, industry or agriculture.
2. Explain what safety measures need to be taken when handling or using each of these isotopes.
* Design a poster to illustrate and explain different technologies that detect radiation, including, but not limited to, a scintillation counter, an electronic personal dosimeter and a thermoluminescent personal dosimeter. Indicate how each technology may be used to monitor radiation in the workplace.
* Chadwick discovered the neutron in 1932 when he bombarded beryllium with alpha particles from polonium.
1. Explain how neutrons are generated to start the fission reaction inside a nuclear reactor.
2. Explain how the properties of neutrons allow them to be used as a probe to investigate matter at ANSTO.
3. X-rays and neutrons are both used for diffraction experiments to investigate materials. Use our current understanding of atomic theory to explain why x-rays and neutrons produce different but complementary diffraction data about a material.
4. Summarise a recent research project from the Australian Centre for Neutron Scattering, where scientists used neutrons to determine the atomic or molecular structures of materials.
5. Neutrons are a particularly penetrative form of radiation. Give examples of safety measures used by ANSTO staff to work safely with neutrons.
* From 1908 to 1913, Geiger and Marsden’s gold foil experiments led to the discovery of positively charged particles in the nucleus of the atom, later termed “protons” by Rutherford.
1. Explain, using labelled diagrams, how a cyclotron is used to accelerate protons at a target. Include the origin of the protons in your answer.
2. Using balanced decay equations, give an example of a proton-rich, cyclotron-produced medical radioisotope and describe its use in patients.
3. The first proton therapy unit in Australia, The Australian Bragg Centre for Proton Therapy and Research, is presently under construction in Adelaide with the building due to be completed in 2023. Describe how this process is currently used in other countries to treat cancerous tumours.
* Joseph Thompson discovered the electron in 1897 when he examined the deflection of cathode rays in electric and magnetic fields.
1. ANSTO uses electron microscopes to develop new high-tech materials for industrial and medical applications. Explain how electrons are used to investigate materials in a scanning electron microscope.
2. The Australian Synchrotron in Melbourne accelerates electrons to almost the speed of light. These electrons are then deflected through magnetic fields to create extremely bright light. Draw an annotated diagram to explain how the Australian Synchrotron works, and summarise one recent example of research performed using this machine.

### Suggested resources

ANSTO. (2018). Historic greenhouse gas concentrations from Antarctic ice core sampling. Data set

[Data sets | ANSTO](https://www.ansto.gov.au/education/resources/data-sets)

ANSTO. (2018). OPAL research reactor. Website.

<https://www.ansto.gov.au/about/how-we-work/how-safe-is-opal>

Australian Microscopy and Microanalysis Research Facility. (2018). Myscope Outreach. Website. <http://myscopeoutreach.org/>

ANSTO. (2017). Australian Synchrotron: Discoveries with light workbook. Workbook <https://www.ansto.gov.au/education/secondary/workbooks-and-datasets>

ANSTO. (2016). Cyclotrons and PET scans fact sheet. [https://www.ansto.gov.au/education/secondary/workbooks-and-datasets](http://www.ansto.gov.au/workbooks)

ANSTO. (2015). Echidna: High-resolution powder diffractometer. Video

[High resolution powder diffractometer - Echidna - YouTube](https://www.youtube.com/watch?v=qqGuhquL990)

ANSTO. (2015). OPAL research reactor animation. Video.

[OPAL research reactor animation - YouTube](https://www.youtube.com/watch?v=GooWJywwfgo)

ANSTO. (2015). PET scan animation. Video.

[PET Scan animation - YouTube](https://www.youtube.com/watch?v=oySvkmezdo0)

ANSTO. (2015). Radiocarbon dating on ANSTO’s VEGA accelerator. Video.

[Radiocarbon dating on ANSTO’s VEGA accelerator - YouTube](https://www.youtube.com/watch?v=luqIDHrwR_w)

ANSTO. (2014). Celebrating Crystallography. News article.

[Celebrating crystallography - New video | ANSTO](https://www.ansto.gov.au/news/celebrating-crystallography-new-video)

ANSTO. (2018). Latest news articles. Website.

<https://www.ansto.gov.au/news>

ANSTO. (2011). Production and decay of radioisotopes. Workbook. [https://www.ansto.gov.au/education/secondary/workbooks-and-datasets](http://www.ansto.gov.au/workbooks)

ANSTO. (2014). Curiosity files (crystallography and neutron diffraction). Workbook. [https://www.ansto.gov.au/education/secondary/workbooks-and-datasets](http://www.ansto.gov.au/workbooks)

## Topic 2: Applications of fission and fusion

### Suggested activities

* Explain the requirements needed to achieve a sustained and controlled nuclear fission reaction in a fission reactor.
* Describe the demonstration of the first self-sustaining nuclear chain reaction at the University of Chicago in 1942.
* Fission reactions occur in both research reactors and power reactors.
1. Construct a table to compare the structure and function of a research reactor (such as OPAL) with a power reactor.
2. One fission reaction that occurs in a nuclear reactor is the bombardment of a U-235 nucleus with a neutron to produce Ba-141 and Kr-92 as well as three neutrons.
	* 1. Write a nuclear equation for this reaction.
		2. Using data from the following website, calculate the energy released in this reaction (<https://www.nist.gov/pml/atomic-weights-and-isotopic-compositions-relative-atomic-masses>).
3. The PRIS public web site (<http://www.iaea.org/pris>) provides information on global nuclear power reactor statistics to the general public. Create a poster to increase public awareness about the use of nuclear power, including the current use of nuclear reactors for the production of electricity throughout the world. Consider the future of this industry in terms of the proposed next generation (generation IV) of nuclear reactors.
* A particularly favourable fusion reaction for use in fusion reactors involves the fusion of deuterium (H-2) and tritium (H-3), producing a Helium nucleus (He-4) and a neutron (n).
1. Write a nuclear equation for this reaction. Using data from the PRIS public web site shown in the previous question, calculate the energy released in this reaction.
2. Explain one way in which this reaction could be carried out in a reactor.
* Analyse progress in the development of fusion reactors. Discuss the availability of the fuel being used, the advanced materials required and an evaluation of the potential use of this reactor for the production of electricity.
* Write an opinion piece for the Sydney Morning Herald, justifying the need for scientific research into fusion reactors.

### Suggested resources

ANSTO. (2018). How safe is OPAL? Website.

<https://www.ansto.gov.au/about/how-we-work/how-safe-is-opal>

ANSTO. (2018). Fusion research in Australia. News article.

[Fusion research in Australia | ANSTO](https://www.ansto.gov.au/news/fusion-research-australia)

Australian ITER forum. (2018). What is fusion energy? Website. <https://fusion.ainse.edu.au/home/what-is-fusion-energy/>

Australian National University. (2018). Australian Plasma Fusion Research Facility. Website. <https://science.anu.edu.au/research/facilities/australian-plasma-fusion-research-facility>

ITER. (2018). ITER. Website.

<https://www.iter.org/>

Tollefson, J. (2018). MIT launches multimillion-dollar collaboration to develop fusion energy. Nature News.

<https://www.nature.com/articles/d41586-018-02966-3>

Touran, N. (2018). Nuclear Power Plants. WhatIsNuclear Website. <https://whatisnuclear.com/reactors.html>

Cartlidge, E. (2017). Europe pauses funding for €500 million fusion research reactor. Nature News. <https://www.nature.com/news/europe-pauses-funding-for-500-million-fusion-research-reactor-1.22165>

Da Silva, W. (2017). Laser-boron fusion now ‘leading contender’ for energy. News article (UNSW). <https://newsroom.unsw.edu.au/news/science-tech/laser-boron-fusion-now-%E2%80%98leading-contender%E2%80%99-energy>

Parliament of Australia. (2017). Generation IV Nuclear Energy – Accession. Parliamentary Inquiry. <https://www.aph.gov.au/Parliamentary_Business/Committees/Joint/Treaties/NuclearEnergy/Report_171/section?id=committees%2Freportjnt%2F024073%2F24682>

# Spyrou, A. and Mittig, W. (2017). Atomic Age Began 75 Years Ago with the First Controlled Nuclear Chain Reaction. The Conversation US (Dec 3, 2017). <https://www.scientificamerican.com/article/atomic-age-began-75-years-ago-with-the-first-controlled-nuclear-chain-reaction/>

ANSTO. (2016). Nuclear techniques measure damage in superconducting cables for fusion energy research reactor. News article.

[Nuclear techniques measure damage in superconducting cables for fusion energy research reactor | ANSTO](https://www.ansto.gov.au/news/nuclear-techniques-measure-damage-superconducting-cables-for-fusion-energy-research-reactor#:~:text=Nuclear%20techniques%20measure%20damage%20in%20superconducting%20cables%20for,plasma%20inside%20the%20vacuum%20vessel%20of%20the%20reactor.)

Gary, S. (2016). Fusion vs fission: clean, green nuclear energy technologies explained. News article (ABC Science).

<http://www.abc.net.au/news/science/2016-02-08/clean-nuclear-energy-are-we-there-yet/6777180>

ANSTO. (2015). OPAL research reactor animation. Video.

[OPAL research reactor animation - YouTube](https://www.youtube.com/watch?v=GooWJywwfgo)

Ball, P. (2014). Laser fusion experiment extracts net energy from fuel. Nature News. <https://www.nature.com/news/laser-fusion-experiment-extracts-net-energy-from-fuel-1.14710>

## Topic 3: Accelerator Science – cyclotrons, linear accelerators and synchrotrons

### Suggested activities

* An early particle accelerator was developed by John D. Cockcroft and Ernest T. S. Walton. Describe this particle accelerator and outline a scientific discovery that they made with it.
* Cyclotrons can be used to produce nuclear medicines for diagnostic scans.
1. Describe the construction of the first cyclotron by Ernest Lawrence.
2. Create an annotated diagram of a cyclotron to explain its operation, and how it can be used in the production of fluorine-18.
3. Explain why very high energy cyclotrons are not possible.
4. Construct a table to compare a linear particle accelerator and a cyclotron, showing their similarities and differences.
* Using references, write a mock conversation between Sir Mark Oliphant, an Australian physicist, and an interviewer to outline his contribution to particle physics.
* Write a feature article, suitable for publication in a weekend magazine, to justify the ongoing costs to the Australian Government of maintaining and upgrading the Australian Synchrotron to keep it at or above world standards. In your article, outline what the synchrotron does and give examples of discoveries at the Australian Synchrotron that could significantly affect people’s lives.
* Construct a table to compare the Australian Synchrotron in Melbourne and the Large Hadron Collider near Geneva in terms of their purpose, scale, particles accelerated and structure.
* In 1964, two physicists independently proposed the existence of the subatomic particles known as quarks. Construct a timeline to summarise the events that confirmed the existence of quarks and the discovery of different types of quarks.
* Describe the discovery of two particles predicted by the Standard Model of particle physics.

### Suggested resources

American Institute of Physics. (2018). Early particle accelerators. Website. <https://history.aip.org/history/exhibits/lawrence/epa.htm>

American Institute of Physics. (2018). The first cyclotrons. Website. <https://history.aip.org/history/exhibits/lawrence/first.htm#epa>

CERN. (2014). Fifty years of quarks by Cian O'Luanaigh. Website. <https://home.cern/about/updates/2014/01/fifty-years-quarks>

National Museums Scotland. (2018). Cockcroft-Walton generator. Website. <https://www.nms.ac.uk/explore-our-collections/stories/science-and-technology/cockcroft-walton-generator/>

CERN. (2018). The Z boson. Website.

<https://home.cern/about/physics/z-boson>

ANSTO. (2016). Australian Synchrotron: Discoveries with Light workbook. Workbook.

[Secondary Learning Resources | Secondary Science Education | ANSTO](https://www.ansto.gov.au/education/secondary/workbooks)

Australian Synchrotron (2018). Synchrotrons and the Large Hadron Collider (LHC). Article

[Synchrotrons and the Large Hadron Collider (LHC)](http://archive.synchrotron.org.au/about-us/our-facilities/accelerator-physics/synchrotrons-and-the-large-hadron-collider)

Ted Ed. (2013) The Basics of the Higgs boson – Dave Barney and Steve Goldfarb. Video

[The basics of the Higgs boson - Dave Barney and Steve Goldfarb - YouTube](https://www.youtube.com/watch?v=IElHgJG5Fe4)

Pralavorio, C. (2018). Long live the doubly-charmed particle. CERN News article <https://home.cern/about/updates/2018/05/long-live-doubly-charmed-particle>

Billings, L. (2017). LHC Physicists Unveil a Charming New Particle. Scientific American article

<https://www.scientificamerican.com/article/lhc-physicists-unveil-a-charming-new-particle/>

Brewster, S. (2016). A primer on particle accelerators. Website. <https://www.symmetrymagazine.org/article/a-primer-on-particle-accelerators>

ANSTO. (2015). Supplementary Resources - Cyclotrons and PET scans. Factsheet. <https://www.ansto.gov.au/education/secondary/workbooks-and-datasets>

Fermilab. (2014). Inquiring minds - The science of matter, space and time. Website. <http://www.fnal.gov/pub/science/inquiring/matter/ww_discoveries/index.html>

American Physical Society. (2003). This month in physics history – Lawrence and the first cyclotron. Website.

<https://www.aps.org/publications/apsnews/200306/history.cfm>

Carver, J.H., Crompton, R.W., Ellyard, D.G., Hibbard, L.U. and Inall, E.K. (2003). Marcus Laurence Elwin Oliphant (1901-2000). Australian Academy of Science. Article. <https://www.science.org.au/fellowship/fellows/biographical-memoirs/marcus-laurence-elwin-oliphant-1901-2000#6>

Wilson, E.J.N. (Unknown). Fifty years of synchrotrons. Article. <http://accelconf.web.cern.ch/accelconf/e96/PAPERS/ORALS/FRX04A.PDF>

Department of Energy Office of Science (Unknown) DOE Explains … the Standard Model of Particle Physics. Article

[DOE Explains...the Standard Model of Particle Physics | Department of Energy](https://www.energy.gov/science/doe-explainsthe-standard-model-particle-physics)

Wolchover, S., Velasco, S., Reading-Ikkanda, L. (2020). A New Map of All the Particles and Forces. Quanta Magazine article

[A New Map of All the Particles and Forces | Quanta Magazine](https://www.quantamagazine.org/a-new-map-of-the-standard-model-of-particle-physics-20201022/)

Hossenfelder, S (2021). Is the Standard Model of Physics now broken? Scientific American article

[Is the Standard Model of Physics Now Broken? - Scientific American](https://www.scientificamerican.com/article/is-the-standard-model-of-physics-now-broken/)

## Topic 4: Medical physics – production and use

### Suggested activities

* + Prepare an annotated flowchart diagram to describe the life cycle of a commonly used radio-pharmaceutical, from production in OPAL to when it leaves the patient. Use quantitative evidence to assess the risks from radiation exposure to the patient and his/her family.
	+ Nuclear medicines fall into two main categories: diagnosis and treatment.
1. Of the three types of radiation (alpha, beta and gamma), explain which type of radiation is emitted by diagnostic medicines, and which is emitted by therapeutic medicines. Consider the ionisation strength and penetration of each type of radiation to justify your answer.
2. Select one example of a diagnostic and one example of a therapeutic nuclear medicine. Evaluate the effectiveness and safety of each example.
3. Identify which type of radiation is least suited to medical procedures. Explain your answer.
* Write a dialogue between a patient and their doctor about a health condition requiring a nuclear medicine for diagnosis and/or treatment (300 words). Include in your dialogue:-

- Symptoms experienced by the patient

- Possible causes

- Procedures required to diagnose the condition

- Possible treatments

Ensure the doctor explains how the nuclear medicine works, either in the diagnostic scan or as part of the treatment, and reassures the patient about any safety concerns that they may have.

* When identifying, or developing, a medical procedure that relies on a new radioisotope, the scientists need to consider several factors before trials on patients can begin. Some of these factors are:

- Toxicity of the isotope

- Radiation dose delivered to the patient

- Delivery methods to the target organ

- The way it is excreted by the body

- Risks to the family of the patient

Choose a radioisotope now being used in medicine and comment on its safety and design. Do not limit yourself to the factors listed above.

* Write two pages of FAQs (frequently asked questions) that patients may want to ask their doctor before they undergo treatment with a radio-pharmaceutical. Include the answer to each question.
* Write a news article, suitable for publication in the Sydney Morning Herald, explaining a clinical trial now underway in Australia of a new radio-pharmaceutical. Explain what it is, how the radiation is generated, how that radiation is delivered to the right organ in the body, in what way is it novel, the expected results from the trial and the advantages over current treatments.
* Write a feature article, suitable for publication in a weekend magazine, to justify the production of radio-pharmaceuticals in Australia, rather than importing them. Discuss impacts on both the patient and the broader community.

### Suggested resources

ANSTO (2022) Mo-99 manufacturing facility

[What Is The Nuclear Medicine Facility? | Mo-99 Production | ANSTO](https://www.ansto.gov.au/products-services/health/facilities/mo-99-manufacturing-facility)

World Nuclear Association. (2021). Radioisotopes in Medicine. Website

[Radioisotopes in Medicine | Nuclear Medicine - World Nuclear Association (world-nuclear.org)](http://www.world-nuclear.org/information-library/non-power-nuclear-applications/radioisotopes-research/radioisotopes-in-medicine.aspx)

ANSTO. (2018). ANSTO fights cancer with a commitment to health research. News article. [ANSTO fights cancer | ANSTO](https://www.ansto.gov.au/news/ansto-fights-cancer)

ANSTO (2019) Innovative Cancer Research. News article.

[Innovative cancer research | ANSTO](https://www.ansto.gov.au/news/innovative-cancer-research)

Currie, G. (2017). Nuclear medicine explainer. Video. <https://www.youtube.com/watch?v=98zuh9S2L7o>.

Currie, G. (2016). Nuclear medicine comes from nuclear reactors. Sydney Morning Herald (25/2/16). News article.

<http://www.smh.com.au/comment/nuclear-medicine-comes-from-nuclear-reactors-20160225-gn3dlg.html>.

ANSTO (2020) Sodium Iodide Therapy Capsule Consumer Information

[Sodium Iodide (131I) Therapy Capsule Consumer Information 2020.pdf (ansto.gov.au)](https://www.ansto.gov.au/sites/default/files/2020-05/Sodium%20Iodide%20%28131I%29%20Therapy%20Capsule%20Consumer%20Information%202020.pdf)

ANSTO (2019) Progress on advanced prostate cancer. News article.

[Progress on advanced prostate cancer | ANSTO](https://www.ansto.gov.au/news/progress-on-advanced-prostate-cancer)

ANSTO (2021) Successful clinical trial for prostate cancer enabled by ANSTO. News article.

[Successful clinical trial for prostate cancer enabled by ANSTO | ANSTO](https://www.ansto.gov.au/news/successful-clinical-trial-for-prostate-cancer-enabled-by-ansto)

United Nations Environment Programme. (2016). Radiation: Effects and sources. Booklet. <http://www.unscear.org/unscear/en/publications/booklet.html>

Sydney Morning Herald. (2018). From Lucas Heights to PeterMac, new prostate therapy is a game changer. News article. 9 May 2018.

<https://www.smh.com.au/national/from-lucas-heights-to-petermac-new-prostate-therapy-is-a-game-changer-20180508-p4ze1f.html>

## Topic 5: Monitoring radiation and Radioactive waste management

### Introduction

Radiation needs to be monitored for two main reasons: to ensure we are all safe (i.e. not being over exposed to radiation) at work and elsewhere, and to ensure that the materials we create at ANSTO receive the correct dose.

ANSTO monitors four types of radiation: alpha, beta, gamma and neutron

Radiation needs to be measured to determine its intensity and the amount of damage it might cause.

The dose that is absorbed depends on the material that is receiving the radiation, the intensity of that radiation and the duration of exposure.

Different types of monitors are needed, depending on the reason for taking the reading.

### Suggested activities

* + Describe three examples of products that require radiation during production.
	+ Explain how different types of radiation cause different effects in human biological cells.
	+ Explain why some monitors measure instantaneous levels of radiation, while others measure accumulated dose. Describe a situation for each type when it is being used appropriately. What types of monitors are used routinely by ANSTO staff when working on site: **not** when working in a high radiation area.
	+ Write down the units used to measure

a) the amount of radiation being released, and

b) how much is being absorbed.

Suggest an upper value of the amount of radiation absorbed for one radiation type that could be tolerated by a normal person without causing long term harm. Indicate how that value was determined.

* Compare and contrast the following units to measure radiation: Sv, Bq, Gy. Identify the most relevant units when working in medical physics and explain your reasoning.
* The new ANSTO Nuclear Medicine (ANM) facility will increase Australia’s production of molybdenum-99 to satisfy 25 to 30% of world demand. With the benefits of nuclear medicines comes the responsibility of managing the radioactive waste that results from the production process. Design a flyer for the local community living near ANSTO to explain how this waste is managed and to allay fears that people living near the site might have about it.
* ANSTO stores intermediate level waste from reprocessed spent reactor fuel and by-products of radiopharmaceutical production. This waste is often long-lived and requires secure and shielded storage. Compare and contrast the two main methods of storing intermediate level waste: immobilisation in glass (vitrification) and Synroc.

### Suggested resources

International Atomic Energy Agency (2019) Measuring Radiation. Video.

[Measuring Radiation | IAEA](https://www.iaea.org/newscenter/multimedia/videos/measuring-radiation)

ANSTO. (2018). A day in the life of OPAL:

[www.ansto.gov.au/news/a-day-life-of-opal-multi-purpose-research-reactor%E2%80%94part-3-evening](http://www.ansto.gov.au/news/a-day-life-of-opal-multi-purpose-research-reactor%E2%80%94part-3-evening)

ANSTO. (2018). A day in the life of a radioactive waste worker. Video.

## [Day in the Life of a Radioactive Waste Worker - YouTube](https://www.youtube.com/watch?v=Vy0LEeli84w)

ANSTO. (2017). Managing waste at ANSTO (webpage).
<https://www.ansto.gov.au/education/nuclear-facts/managing-waste>

Department of Industry, Innovation and Science. (2017). National Radioactive Waste Management Facility. Webpage.

[Australian Radioactive Waste Agency | Department of Industry, Science, Energy and Resources](https://www.industry.gov.au/policies-and-initiatives/australian-radioactive-waste-agency)

# ARPANSA. National Radioactive Waste Management Facility - Radioactive waste. Webpage.

[National Radioactive Waste Management Facility - Radioactive waste | ARPANSA](https://www.arpansa.gov.au/regulation-and-licensing/safety-security-transport/radioactive-waste-disposal-and-storage/radioactive-waste)

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ANSTO. (2018). Synroc waste treatment plant.
<https://www.ansto.gov.au/news/synroc-australian-innovation-increases-technology-readiness-for-waste-treatment-plant>

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ANSTO. (2015). Safely managing Australia’s radioactive waste. Video.

[Safely Managing Australia's Radioactive Waste - YouTube](https://www.youtube.com/watch?v=4mDuX--vzH8)