(Project Number: 945301)

# DELIVERABLE D5.5

# High School Teaching Package

Lead Beneficiary: NNL

Due date: 30/09/2023 Released on: 26/09/2023


| | |
|---|---|
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| For the Lead Beneficiary | Reviewed by Work package Leader | Approved by Coordinator |
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Start date of project: **01/10/2020** Duration: **36 Months**
Project Coordinator: Assoc. Prof Mojmír Němec
Project Coordinator Organisation: CTU VERSION: 1.3


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|---|---|---|
| **Dissemination Level** | | |
| **PU** | Public | **X** |
| **RE** | Restricted to a group specified by the Beneficiaries of the A-CINCH project | |
| **CO** | Confidential, only for Beneficiaries of the A-CINCH project | |

**Version control table**

| Version number | Date of issue | Author(s) | Brief description of changes made |
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*"This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945301."*

# EXECUTIVE SUMMARY

The purpose of this report is to summarise activities related to the delivery of the A-CINCH High School Work Package and its evaluation. The aim of the work package was to develop a lesson package for 16-18 year olds that introduced them to radiochemistry topics. Two different lesson packages have been developed, tested and finalised. One lesson focuses on nuclear medicine chromatography, the other lesson cover pyro-processing and electrochemical cells.

93 students and 10 teachers/STEM ambassadors have taken part in the lesson package trials and provided feedback on the lessons. Overall, positive feedback was received from the trials with 90% of students interested in learning more about nuclear chemistry after the workshops and 100% of teachers agreeing that the workshops were an interesting way to showcase how chemistry can be applied practically.

The lesson packages have been designed so that workshops can be delivered independently by teachers and STEM ambassadors. The resources have been uploaded to the CINCH HHUB, to NNL's Outreach database, and to the STEM Community website to allow public access and use of the resources.

CONTENT

# 1 INTRODUCTION

Two separate radiochemistry lesson packages for 16-18 year olds have been developed. The lessons have been linked to the high school curriculum and have been designed so that teachers and STEM ambassadors can deliver the workshops independently. The first lesson explores nuclear medicine and chromatography using a virtual online experiment. The second lesson explains how electrochemical cells are used in pyro-processing to create a closed nuclear fuel cycle.

## 1.1 Development of Nuclear Medicine Lesson Package

In the previous CINCH project, MEET-CINCH, a pilot version of a lesson package using the IonLab (a robotic nuclear radio chemistry experiment) to separate a radioisotope used in nuclear medicine was created. During the initial phase of the A-CINCH project, the focus of work on D5.5 was to create a new and improved version of this lesson package.

Initially, the live IonLab was incorporated into the lesson through a video stream, however, this meant only the teacher could carry out the experiment with the students watching, and the teacher had to get in contact with LUH in advance to arrange the setup of the IonLab. To solve these issues, LUH designed a virtual Interactive Screen Experiment (ISE) based on the IonLab for the improved lesson package, this reduced IT problems and allowed several students to perform the experiment with different parameters at the same time.

As well as the ISE, an animated introductory video was created for the lesson. Work was carried out with UNIVLEEDS to produce a three-minute video that explains the theory of radioisotopes and how they are used in Nuclear Medicine. The video has been designed to be played at the start of the lesson and can be found here: What are medical radioisotopes?. As an extension activity after the lesson, a link and prompt to access D5.3 - UNIVLEEDS Career Case Study videos has been included in the teacher guide.

The Nuclear Medicine lesson package includes the following resources: the ISE, an introductory video, a PowerPoint presentation to structure the lesson, a teacher guide that provides a walkthrough of the lesson, and a student workbook that provides experiment instructions and extension activities. These can be seen in Annex 1.

## 1.2 Development of Pyro-Processing Lesson Package

The second lesson package focuses on Pyro-Processing. The lesson was linked to the high school curriculum through the topic of electrochemical cells and redox reactions. The lesson begins with an animated video that introduces students to the topic of Pyro-Processing - Pyrochemical Processing: A Sustainable Solution for Nuclear. This is followed by the teacher going through an explanation of the theory of electrochemical cells and how they are used in Pyro-Processing to create a closed nuclear cycle. The students then carry out an experiment to build their own electrochemical cell and relate this to the separation of spent nuclear fuel. After the experiment, the students complete an activity to draw a closed nuclear fuel cycle and a crossword based on the theory of the lesson. The lesson finishes with a round up discussion about the experiment and extension activities that encourage students to consider whether they would support an open or closed nuclear fuel cycle and what kind of energy future they would like.

As with the Nuclear Medicine lesson package, the pyro-processing lesson contains an introductory video, a PowerPoint presentation, a teacher guide, and a student workbook. It also includes a risk assessment for the electrochemical cell experiment.

## 1.3 Use of Resources after A-CINCH Project

The lesson packages have been designed so that workshops can be delivered independently by teachers and STEM ambassadors without involvement from the A-CINCH team. The resources will be uploaded to the CINCH HUB and to NNL's Outreach database for use in future outreach events. To enable public use of the lesson packages, they have been uploaded to the STEM Community website, this is a forum for STEM educators where resources and discussions on chemistry education are shared - STEM Community.

# 2 WORKSHOP TRIALS AND FEEDBACK

The High School work package has carried out 6 trials with students. The Nuclear Medicine: Chromatography in Action workshop was trialled at a High School and at the 2 A-CINCH Summer Schools. The Pyro-Processing: Electrochemical Cells in Action workshop was trialled at two High Schools. Feedback was collected after each trial to improve the lesson packages.

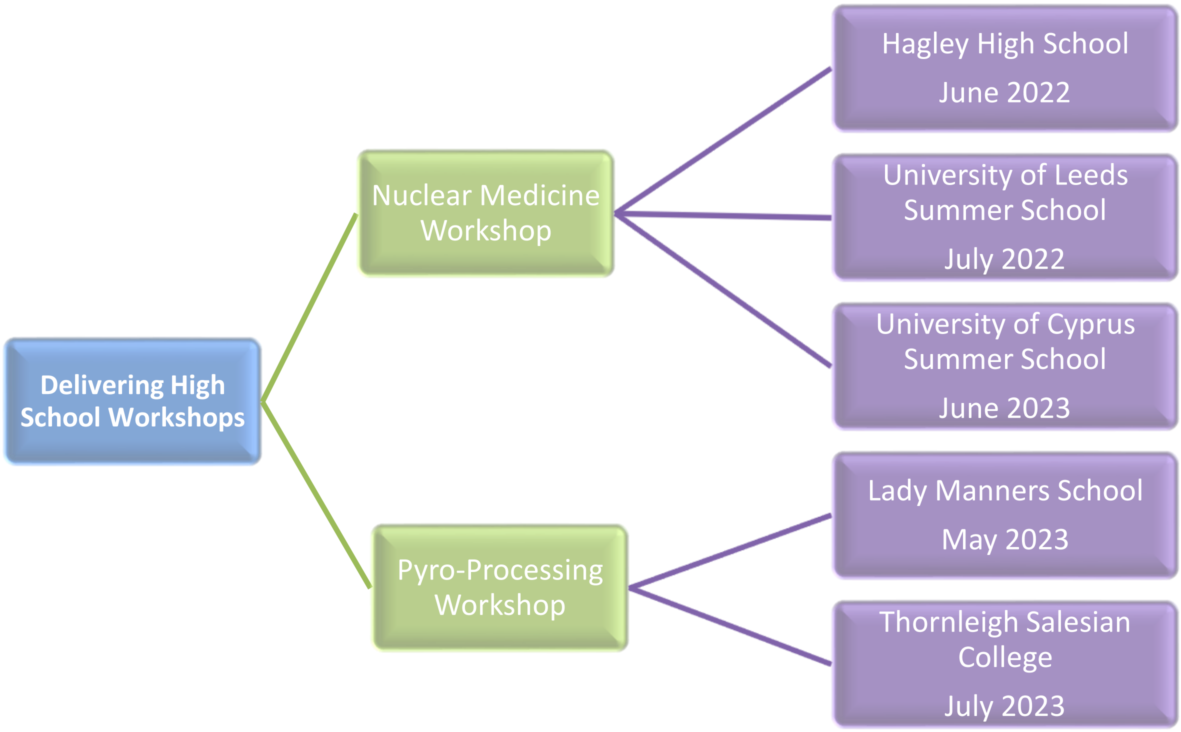



**Figure 1. High School Work Package Trials**

## 2.1 Improvements Made After Trials

During the first school trial of the Nuclear Medicine lesson package, several students encountered similar issues when using the ISE. To solve this, the ISE instructions were rewritten in the student workbook to be clearer and an experiment trouble shooting section was added to the teacher guide. These improvements made a clear difference during the second trial of the lesson with students able to conduct the experiment with greater independence.

Feedback gathered from a teacher on the first draft of the Pyro-Processing lesson suggested that the theory covered in the lesson was too broad and complicated for one lesson. The lesson was then stream-lined to be more concise with content on balancing half equations removed. Conversations with students during the first trial of the Pyro-Processing lesson indicated that students wanted more discussion about nuclear power during the workshop, based on this, an extension activity was added to the lesson that encourages students to consider reasons for and against a closed nuclear fuel cycle and to discuss what they would like the energy supply of the future to look like. This extension activity was positively received in the second trial of the lesson package.

## 2.2 Student Feedback

93 students have taken part in the A-CINCH high school workshops across the project, each of these students was asked to fill in a feedback sheet after the lesson. 99% of the students found the workshops interesting and engaging, with 98% agreeing that they had gained new knowledge and skills. 90% of students were interested in learning more about nuclear chemistry after the workshops and 76% of students agreed that the workshops had made them consider a career related to nuclear science.

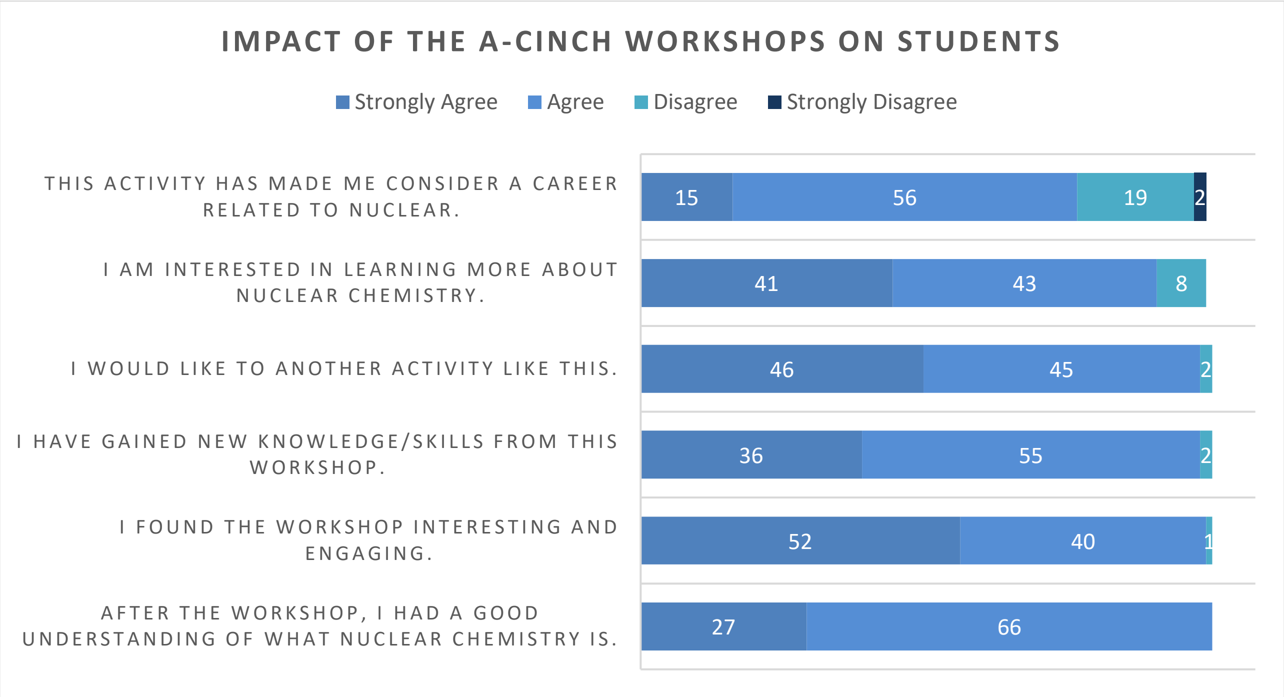



**Figure 2. Student Feedback**

## 2.3 Teacher and STEM Ambassador Feedback

Ten teachers and STEM ambassadors have been involved in the high school workshops and have given positive feedback about the lessons. The teachers felt the workshops were excellent resources to show the real-world applications of the chemistry theory they were teaching. Most importantly, all the teachers and STEM ambassadors strongly agreed that they would feel comfortable delivering the workshops independently with the resources provided.

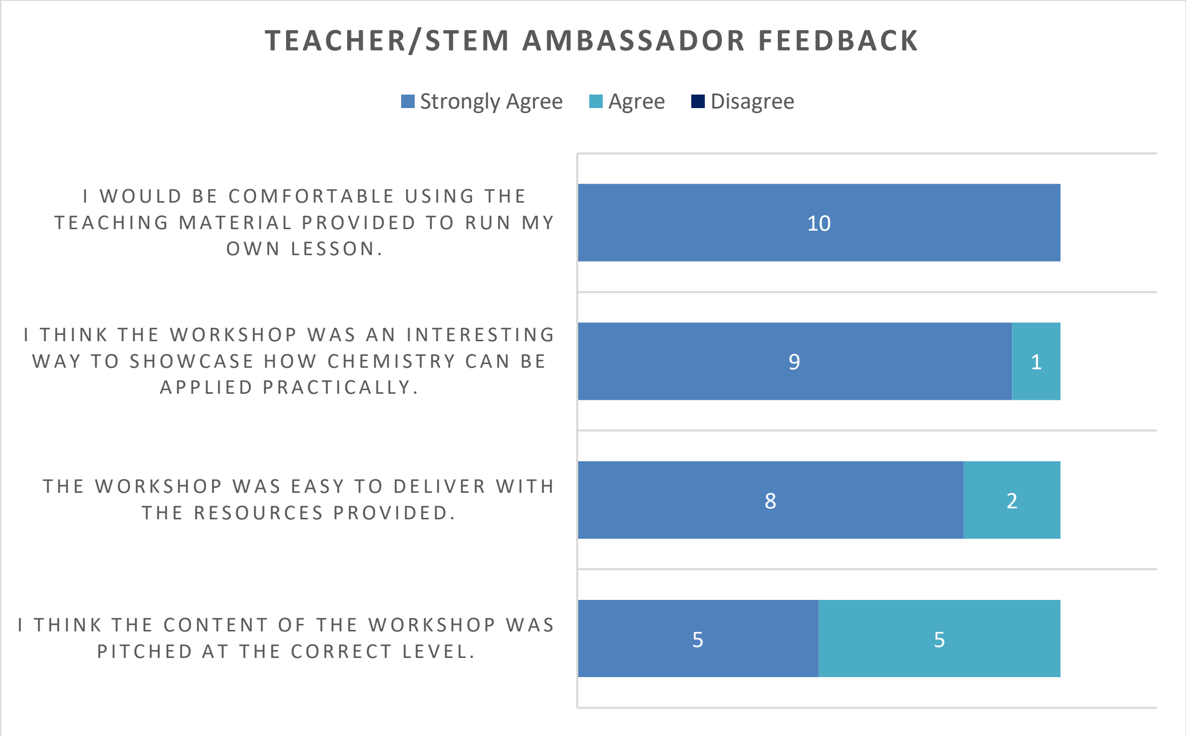



**Figure 3. Teacher Feedback**

# 3 CONCLUSIONS

Two completed lesson packages have been developed titled “Nuclear Medicine: Chromatography in Action” and “Pyro-Processing: Electrochemical Cells in Action”. Six trials of the lesson packages were carried out with 93 students and 10 teachers/STEM ambassadors taking part in the trials. Feedback from the trials was used to improve the lesson packages. Overall, positive feedback was received from the trials with 98% of students agreeing that they had gained new knowledge and skills, and 90% of students interested in learning more about nuclear chemistry after the workshops.

Comments from teachers reflected positively on the fact that the workshops were excellent resources to show the real-world applications of the chemistry theory. All teachers and STEM ambassadors who took part in the trials strongly agreed that they would feel comfortable delivering the workshops independently with the resources provided. The resources have been uploaded to the CINCH HUB, to NNLs Outreach database, and to the STEM Community website to allow for future use of the resources by teachers and STEM ambassadors.

# ANNEXES

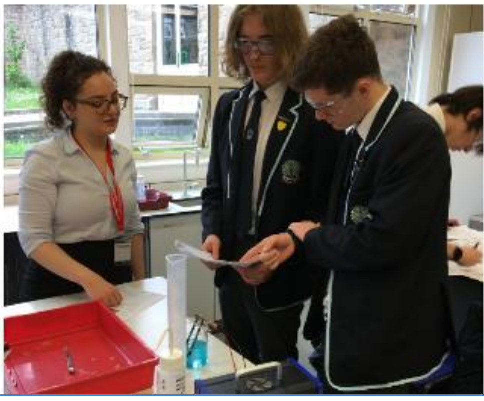
### Annex I: Article From Lady Manners School Workshop

**Lady Manners School**
and Sixth Form

CONTACT US    MENU

We were delighted to welcome Joanna Bland and Cicily Hillebrand into school to deliver a nuclear chemistry workshop to our Y12 chemistry students. Joanna who is an chemist (and an ex-student of LMS) and Cicily who is a chemical engineer delivered an extremely engaging session involving the chemistry of nuclear fuel processing. The techniques that they are working on have the potential to make nuclear energy generation a more efficient and sustainable process with a greatly reduced environmental impact and the students enjoyed applying their understanding of chemistry to this new context. They were also very interested to learn about the career progression that might be expected from working in the chemical sciences and engineering and our visitors gave lots of useful information about their route into these areas and how they see their careers progressing in the future. A huge thank you to Joanna and Cicily for such a rewarding afternoon and well done to Y12 chemists for the positive engagement and many insightful questions that were asked.

Mr Edge




## Annex II: Pyro-Processing Lesson Resources

TEACHER GUIDE

# Pyro-Processing:
## Electrochemical Cells in Action

**Objectives**

- Understand the nuclear fuel cycle and how nuclear fuel generates electricity.
- Explore how pyro-processing can be used to create a closed loop nuclear fuel cycle.
- Investigate electrochemical cells and how they can be used in pyro-processing.
- Conduct an experiment to demonstrate an electrolytic cell.

**Fast facts**

**Subject:** Chemistry
**Age range:** 16–18 years old
**Teacher preparation time:** 20 minutes
**Lesson time required:** 1 hour
**Location:** Science Lab

**Pre-Lesson Preparation Activities**

- Read through the teacher guide.
- Print student worksheets.
- Check the link to the introductory video works.
- Collect equipment for the experiment.

**Overview**

When uranium rods are used as nuclear fuel, they undergo fission to produce energy. However, fission only occurs in a fraction of the uranium in the rods, 95% of the rod remains uranium. Pyro-processing uses an electrochemical cell to recycle the valuable uranium to create new fuel rods.

In this lesson, students will understand how pyro-processing can be used to create a closed nuclear fuel cycle. They will then investigate redox reactions in electrochemical cells and how this enables pyro-processing. Students will conduct an electrolysis experiment using copper (II) sulfate to demonstrate an electrochemical cell.

A student worksheet provides the experiment instructions and has activities for the students to test their knowledge on redox reactions.



TEACHER GUIDE

Pyro-Processing: Electrochemical Cells in Action

**Materials & Equipment**

- Computer and projector or smart screen for the teacher to display the presentation.
- Experiment equipment set for every 2-4 students. 5g of Copper (II) Sulfate, 150ml Water, Beaker, 2 Carbon/Graphite Electrodes, Two Crocodile Clips, Two Wires, DC Power Supply.
- Pyro-processing experiment risk assessment.
- Teacher handbook.
- Student worksheets (one per student).

**Lesson Plan**

| Activity | Duration |
|---|---|
| 1. Welcome and lesson objectives | 5 |
| 2. Pyro-processing animated video | 5 |
| 3. Theory and introduction to experiment. | 10 |
| 4. Carry out the experiment. | 25 |
| 5. Student worksheet activities. | 10 |
| 6. Round up and class discussion. | 5 |
| **Total Duration** | 60 |



TEACHER GUIDE

Pyro-Processing: Electrochemical Cells in Action

**Lesson Walk-through**

1. **Welcome (Slides 1-2)**

*What do you think of when you hear "nuclear chemistry"?* **Nuclear chemistry is used for many purposes including medical treatment & diagnosis, agriculture, dating of fossils, defense and energy generation.** Today we will be looking at the nuclear fuel cycle and pyro-processing. Provide an overview of the learning objectives. Hand out the student worksheets.

2. **Pyrochemical Processing Animation (Slide 3)**

Play the video to introduce the lesson:

- Pyrochemical Processing: A Sustainable Solution for Nuclear https://youtu.be/wEbA-zZSz70

3. **Electrochemical Cells and Redox Reactions Theory (Slides 4 - 6)**

***Slide 4:*** There are two different types of electrochemical cell – electrolytic and galvanic (voltaic) cells. In an electrolytic cell, electrical energy is used to drive a non-spontaneous chemical reaction to occur. It requires a source of electrical energy. In a galvanic cell, the chemical reaction happens spontaneously, and the energy released is converted to electrical energy. This means galvanic cells can be used as fuel cells.

*Pyro-processing uses an electrolytic cell, will the cell circuit require an electrical power supply?* **Yes, electrolytic cells require a source of electrical energy.**

***Slide 5:*** Electrochemical cells use redox reactions. Every cell has two electrodes, one positive and one negative.

The positive electrode is called the anode. As it is positively charged, it attracts negative ions and can accept negatively charged electrons. The negative ions lose electrons at the anode. *What type of reaction are the ions going through if they are losing electrons?* **An oxidation reaction.** Talk through the half equation for the anode, the chlorine is losing electrons.

The negative electrode is called the cathode. As it is negatively charged, it attracts positive ions and can donate electrons. The positive ions gain electrons at the cathode. *What type of reaction are the ions going through if they are gaining electrons?* **A reduction reaction.** Talk through the half equation at the cathode, the sodium is gaining electrons.

Remember OIL RIG, oxidation is a loss and reduction is a gain (of electrons).

***Slide 6:*** In pyro-processing we use an electrolytic cell where we heat up a salt mixture until it is a liquid solvent and then immerse a basket of waste nuclear fuel in it. The liquid salt mixture has to be able to dissolve the waste nuclear fuel.

The basket becomes the anode which is the positively charged electrode. The other electrode is the cathode which is negatively charged. Any negatively charged ions will move towards the positive anode to lose electrons and become neutral. Any positively charged ions will move towards the negative cathode to gain electrons and become neutral.

*Where are oxidation reactions taking place in this cell?* **At the positive anode where ions are losing their electrons.** *Where are reduction reactions taking place in this cell?* **At the negative cathode where ions are gaining electrons.**

The electrons move from the negatively charged ions, to the anode, across to the cathode and then to the positively charged ions. In pyro-processing the useful material in the nuclear waste dissolves into positive ions which move towards the cathode to be reduced. Once they collect on the cathode, they can be removed and formed into new fuel.

**4. Introduction To The Copper (II) Sulfate Experiment (Slides 7-9)**

***Slide 7:*** In school we can't demonstrate this experiment with nuclear waste. So instead, we are going to look at a similar example that uses copper sulfate. We are going to set up two electrodes and connect them with a power supply. As the electrical current is applied, one electrode will become the positive anode and the other will become the negative cathode. The ions will collect at each electrode depending on their charge. Let's see if we can work out what will happen.

***Slide 8:*** In our experiment we will be using aqueous copper (II) sulfate solution. Copper (II) means that the copper ion has a positive 2+ charge. The copper ion will gain two electrons to become neutral. It will become a solid.

*Is this a reduction or oxidation reaction?* **The copper is undergoing a reduction reaction because it is gaining electrons.**

*What will we expect to see in the experiment to know that this reduction taken place?* **The copper should collect on the negative cathode as a solid.**

***Slide 9:*** Talk through the experimental setup. The experiment procedure is explained in the student worksheet.

**5. Running The Experiment**

Divide the students into groups of 2-4 and allow them to collect their experiment equipment. Please read through the experiment risk assessment.

There are several ways of securing the graphite electrodes, you can use retort stands and clamps or they can also be fixed using Blutac onto a small strip of wood resting on the top of the beaker. Explain the option you choose to the students.

Students are told to clean the graphite electrodes at the end of the experiment with emery paper.

**6. Experiment Teaching Notes**

Students should see a deposit of copper forming on the cathode. This will often be powdery and uneven.

- Bubbles of gas (oxygen) are formed at the anode.
- Cathode reaction: $Cu^{2+}_{(aq)} + 2e^{-} \rightarrow Cu_{(s)}$
- Anode reaction: $2H_2O_{(l)} \rightarrow O_{2(g)} + 4H^{+}_{(aq)} + 4e^{-}$
- With carbon (graphite) electrodes, the





**7. Student Worksheet Exercises**

If the students complete the experiment early and have cleared up, there are exercises in the student worksheet on electrochemical cells and nuclear chemistry.

**8. Class Discussion**

- Did the experiment go as expected?
- Were our predictions about copper collecting on the cathode correct?
- Where would the sulfate ions move to in the beaker? *Towards the anode as they are negatively charged.*
- Why is pyro-processing useful for the nuclear fuel cycle? *It allows us to separate valuable uranium fuel from waste spent fuel. This means we can recycle nuclear fuel from reactors and create a closed nuclear fuel cycle. Less uranium would have to be mined and nuclear energy would become more sustainable and produce less waste.*

**9. OPTIONAL IF THERE IS TIME**

A. Display the video:

- Nuclear Power and Climate Change (2 minutes, 30 seconds) https://youtu.be/J0k2BSHTrS4

This video explains how nuclear power can complement renewable energy sources in the transition to a low-carbon energy future. After the video, discuss:

- What is the issue with just using renewable energy sources such as wind, solar & tidal power?
- Why would we want to develop a closed nuclear cycle?
- Can you think of any reasons why we wouldn't develop a closed cycle? (Answer: Expensive!)
- If it was up to you, would you want a closed or an open nuclear fuel cycle?

B. Split the students into groups and get them to consider the following scenarios:

- If you were designing a new national energy grid, which energy sources would you use?
- An energy company wants to build a nuclear plant in your town, will you support the build?

Ask the groups to share their decision with the class and explain their reasoning.

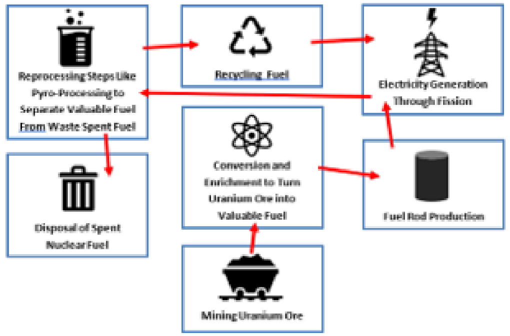
C. Ask students to complete their student worksheet exercises. This can also be completed after the lesson as a follow up.

An additional lesson "Nuclear Medicine: Chromatography in Action" can be found through the A-CINCH project website: https://www.cinch-project.eu/links or by searching the STEM Learning Community website: https://community.stem.org.uk/

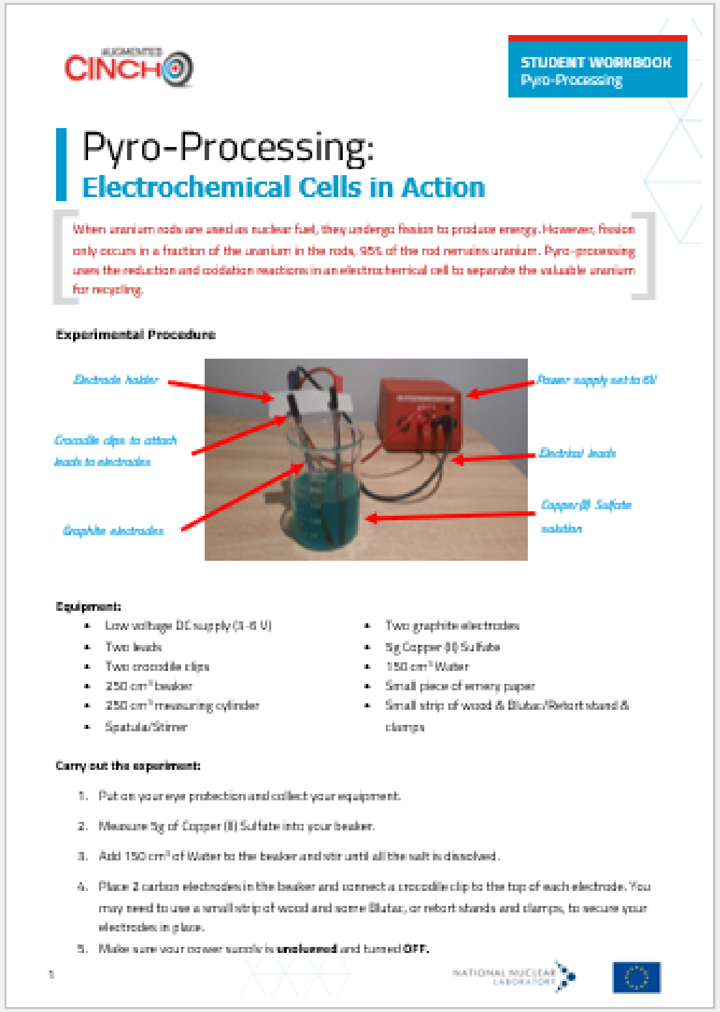




**Worksheet Answers**




| | | | |
|---|---|---|---|
| **Across 1** | Copper | **Down 1** | Cathode |
| **Across 2** | Renewable | **Down 2** | Anode |
| **Across 3** | Reduction | **Down 3** | Electron |
| **Across 4** | Donors | **Down 4** | Positive |
| **Across 5** | Pyroprocessing | **Down 5** | Cycle |
| **Across 6** | Increase | **Down 6** | Oxidation |
| **Across 7** | Uranium | **Down 7** | Nuclear |
| **Across 8** | Redox | **Down 8** | Oxidising |
| **Across 9** | Negative | **Down 9** | Current |
| | | **Down 10** | Charged |
| | | **Down 11** | Ion |



STUDENT WORKBOOK
Pyro-Processing

# Pyro-Processing:
## Electrochemical Cells in Action

When uranium rods are used as nuclear fuel, they undergo fission to produce energy. However, fission only occurs in a fraction of the uranium in the rods, 95% of the rod remains uranium. Pyro-processing uses the reduction and oxidation reactions in an electrochemical cell to separate the valuable uranium for recycling.

**Experimental Procedure**



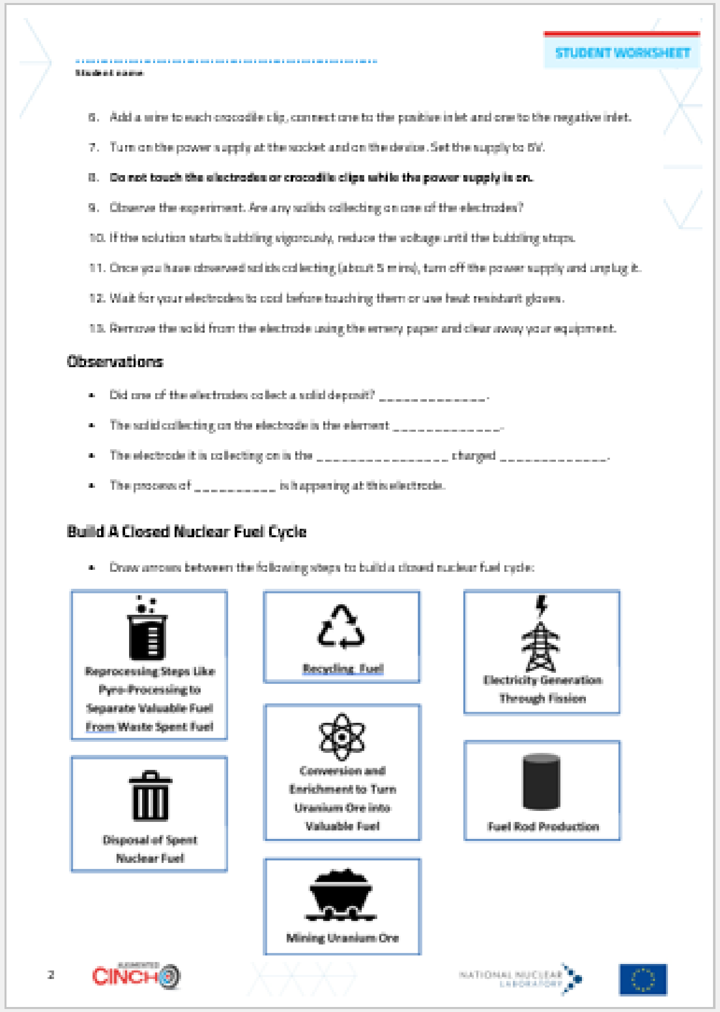
**Equipment:**

- Low voltage DC supply (3-6 V)
- Two leads
- Two crocodile clips
- 250 cm³ beaker
- 250 cm³ measuring cylinder
- Spatula/Stirrer
- Two graphite electrodes
- 5g Copper (II) Sulfate
- 150 cm³ Water
- Small piece of emery paper
- Small strip of wood & Blutac/Retort stand & clamps

**Carry out the experiment:**

1. Put on your eye protection and collect your equipment.
2. Measure 5g of Copper (II) Sulfate into your beaker.
3. Add 150 cm³ of Water to the beaker and stir until all the salt is dissolved.
4. Place 2 carbon electrodes in the beaker and connect a crocodile clip to the top of each electrode. You may need to use a small strip of wood and some Blutac, or retort stands and clamps, to secure your electrodes in place.
5. Make sure your power supply is **unplugged** and turned **OFF**.

1



STUDENT WORKSHEET

Student name

6. Add a wire to each crocodile clip, connect one to the positive inlet and one to the negative inlet.
7. Turn on the power supply at the socket and on the device. Set the supply to 6V.
8. **Do not touch the electrodes or crocodile clips while the power supply is on.**
9. Observe the experiment. Are any solids collecting on one of the electrodes?
10. If the solution starts bubbling vigorously, reduce the voltage until the bubbling stops.
11. Once you have observed solids collecting (about 5 mins), turn off the power supply and unplug it.
12. Wait for your electrodes to cool before touching them or use heat resistant gloves.
13. Remove the solid from the electrode using the emery paper and clear away your equipment.

**Observations**

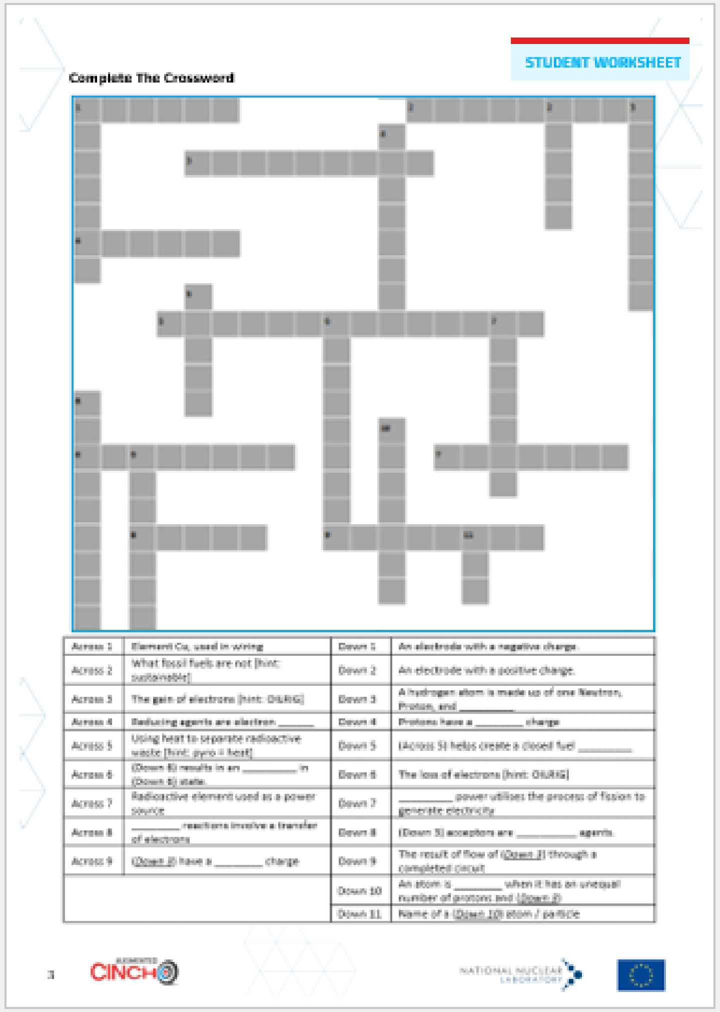
- Did one of the electrodes collect a solid deposit? _____________.
- The solid collecting on the electrode is the element _____________.
- The electrode it is collecting on is the _______________ charged _____________.
- The process of _________ is happening at this electrode.

**Build A Closed Nuclear Fuel Cycle**

- Draw arrows between the following steps to build a closed nuclear fuel cycle:



2



STUDENT WORKSHEET

**Complete The Crossword**

| | | | |
|---|---|---|---|
| Across 1 | Element Cu, used in wiring | Down 1 | An electrode with a negative charge. |
| Across 2 | What fossil fuels are not [hint: sustainable] | Down 2 | An electrode with a positive charge. |
| Across 3 | The gain of electrons [hint: OILRIG] | Down 3 | A hydrogen atom is made up of one Neutron, Proton, and _________ |
| Across 4 | Reducing agents are electron _______ | Down 4 | Protons have a ________ charge |
| Across 5 | Using heat to separate radioactive waste [hint: pyro = heat] | Down 5 | (Across 5) helps create a closed fuel _________ |
| Across 6 | (Down 6) results in an _________ in (Down 6) state. | Down 6 | The loss of electrons [hint: OILRIG] |
| Across 7 | Radioactive element used as a power source | Down 7 | _________ power utilises the process of fission to generate electricity |
| Across 8 | ________ reactions involve a transfer of electrons | Down 8 | (Down 3) acceptors are _________ agents. |
| Across 9 | (Down 3) have a ________ charge | Down 9 | The result of flow of (Down 3) through a completed circuit |
| | | Down 10 | An atom is ________ when it has an unequal number of protons and (Down 3) |
| | | Down 11 | Name of a (Down 10) atom / particle |

3

AUGMENTED CINCH

RISK ASSESSMENT

# Pyro-Processing: Electrochemical Cells in Action

| | | | |
|---|---|---|---|
| **Activity** | Electrochemical cell experiment – electrolysis of copper (II) sulfate. | **Demonstrator(s)** | |
| **Date** | | **Venue** | |
| **Event Organiser** | | **Audience** | 16-18 year olds |
| **Activity Description** | The students will carry out the electrolysis of copper (II) sulfate solution to mimic the electrochemical cell used in pyro-processing. The experiment being carried out is part of a lesson that teaches students about the chemistry involved in a closed nuclear fuel cycle. | | |

| Hazards | Control Measures |
|---|---|
| **Chemical hazards (copper (II) sulfate)**<br>Mild corrosive to metal surfaces. Chemicals have the potential to cause irritation or damage to skin and eyes. Chemicals have the potential to cause irritation or damage if ingested. Solid copper (II) sulfate and concentrated copper (II) sulfate solutions are toxic to aquatic life. | • Clean up equipment for spills is available.<br>• Eye wash stations are in immediate vicinity.<br>• Appropriate PPE is worn (including safety glasses). Lab coats and gloves may also be worn.<br>• Equipment to be inspected for visual faults.<br>• Dilute and dispose of copper (II) sulfate appropriately. |
| **Electrolysis of saltwater**<br>Risk of an electrical issue that potentially could cause burning, electrocution or damage to electrical devices. Electrodes have the potential to heat up, this runs a risk of burning the user or potentially start a fire if using carbon electrodes. | • Experiments to be carried out in a well-ventilated space.<br>• Electrolysis equipment to be turned off until use.<br>• Electrodes should be left to cool after the experiment is complete or heat resistant gloves should be worn when handling electrodes after the experiment.<br>• Equipment to be inspected for visual faults. |
| **Electrical hazards from benchtop equipment and instruments**<br>Equipment can suffer ingress of water leading to damage to equipment with the possibility of electrocution. Equipment can be damaged leading to exposed conductive material with the possibility of electrocution. | • Low voltage/current equipment is used, all equipment is stored away from water supplies.<br>• Equipment to be inspected for visual faults and to ensure PAT label is in date before work commences. |



NATIONAL NUCLEAR LABORATORY

AUGMENTED CINCH

RISK ASSESSMENT

| Hazards | Control Measures |
|---|---|
| **Manual handling**<br>Operators suffering sprains, strains whilst moving or carrying vessels containing reagents, instrumentation items. | • No heavy lifting is involved in experiment. |
| **Glassware hazards**<br>Operators could be cut or lacerated by broken glassware. This could also result in damage to eyes from shards/projectiles/glass splinters | • Appropriate PPE is worn (including safety glasses) and equipment provided to clean up broken glass without directly touching the glass.<br>• Broken glassware is to be swept up disposed of via glass bin. |
| **Slips and trips whilst performing experiment**<br>Slipping on spilled liquids or tripping on obstacles. | • Appropriate footwear and clothing are to be used to minimise slip risk.<br>• Spill kits and wet floor signage are available in the immediate vicinity. |

In addition to the above control measures, the following standard safety requirements should also be in place:

- The demonstrator and any participants should wear appropriate PPE at all times. This PPE should be checked to be in good condition, of the correct specification for the hazards in the activity and appropriately CE/UKCA marked.
- Appropriate ventilation and hygiene facilities should be present.
- Minimum quantities and concentrations of hazardous substances should be used during the activity.
- Appropriate neutralisers, such as eyewash bottles, should be available.
- Appropriate fire extinguishing equipment, according to the materials present, should be present.

Signature: ……………………………………………………………………………….

Print Name: ……………………………………………………………………………….

Date: ……………………………………………………………………………….



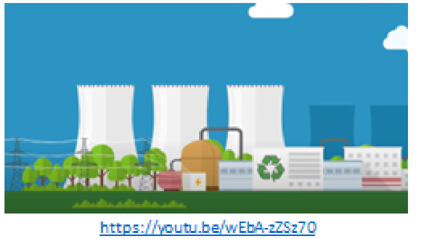
NATIONAL NUCLEAR LABORATORY

Augmented cooperation in education and training in nuclear and radiochemistry

# Pyro-Processing:
## Electrochemical Cells in Action

1

## Introductory Video



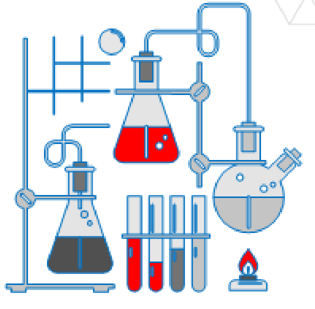
https://youtu.be/wEbA-zZSz7Q



3

## Learning Objectives

- Understand the nuclear fuel cycle and how nuclear fuel generates electricity.
- Explore how pyro-processing can be used to create a closed loop nuclear fuel cycle.
- Investigate electrochemical cells and how they can be used in pyro-processing.
- Conduct an experiment to demonstrate an electrolytic cell.





2

## Types of Electrochemical Cell

There are two different types of electrochemical cells – electrolytic and galvanic.

| Electrolytic Cell | Galvanic/Voltaic Cell |
|---|---|
| Changes electrical energy into a chemical reaction. | Changes chemical energy into electrical energy |
| Non-spontaneous reaction occurs. | Spontaneous reaction occurs. |
| Requires an external voltage source. | Does not require an external voltage source. |

Pyro-processing uses an electrolytic cell, will the cell circuit require an electrical power supply?

**Yes! Electrolytic cells require a source of electrical energy.**



4

## Electrolytic Cells

Redox reactions take place in electrolytic cells where electrons are transferred from the reducing agent to the oxidising agent via an external current. All cells have two electrodes.

**Positive Electrode = Anode**

The anode is positive and accepts electrons. Negatively charged ions lose electrons at the anode. These ions go through an __Oxidation__ reaction at the anode.

-1 ⟶ 0

$$2Cl^- \longrightarrow Cl_2 + 2e^-$$

OIL

**Negative Electrode = Cathode**

The cathode is negative and a source of electrons. Positively charged ions gain electrons at the cathode. These ions go through a __Reduction__ reaction at the cathode.

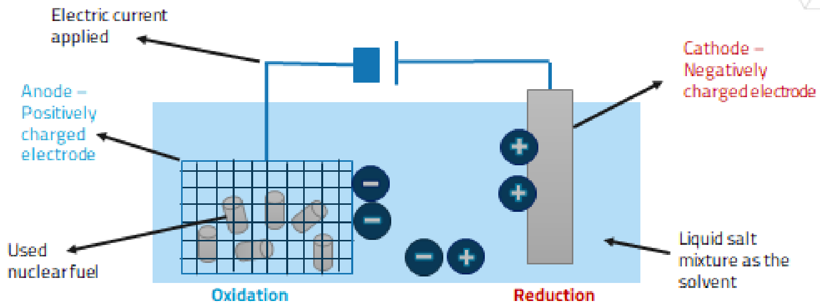
1+ ⟶ 0

$$Na^+ + e^- \longrightarrow Na$$

RIG

5

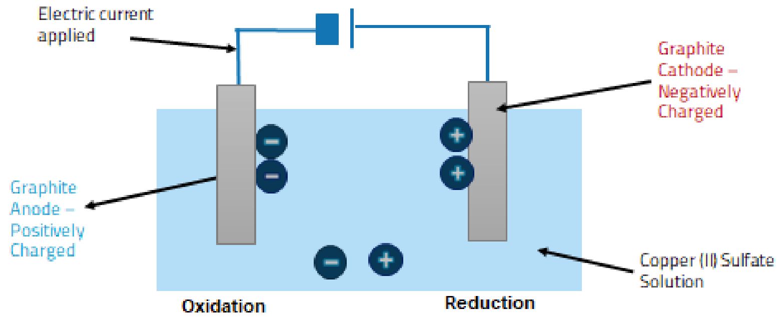
## The Electrochemical Cell in Pyro-Processing




Where are the oxidation and reduction reactions taking place?

6

## Copper (II) Sulfate Cell




7

## Copper (II) Sulfate Reactions

We will be using aqueous copper(II) sulfate solution.

$$Cu^{2+}_{(aq)} + 2e^- \longrightarrow Cu_{(s)}$$

Is this a reduction or an oxidation reaction?

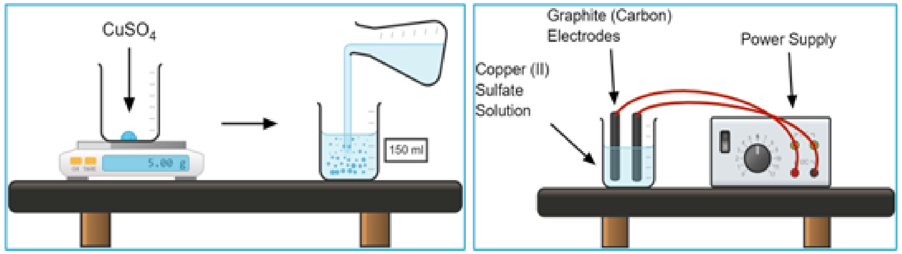
**Reduction**

What do we expect to see in the experiment? How will we know the Copper is being reduced?

**The copper should collect on the negative cathode as a solid.**

8

## Experimental Setup

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**Visit:** National Nuclear Laboratory (nnl.co.uk) to learn more about the work that the UK's National Nuclear Laboratory does.

**Visit:** Augmented CINCH: Augmented CINCH (cinch-project.eu) to learn more about the A-CINCH project.

**Visit:** https://community.stem.org.uk/ **or** https://www.cinch-project.eu/links to access a lesson on Nuclear Medicine: Chromatography in Action.

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# Annex III: Nuclear Medicine Lesson Resources

TEACHER GUIDE

## Nuclear Medicine: Chromatography in Action

### Objectives

- Recap of atomic structure and isotopes.
- Understand what is meant by radioactive decay and half-lives.
- Investigate the theory behind chromatography.
- Conduct a virtual column chromatography experiment to produce a medical radioisotope.
- Explore how radioisotopes can be used in nuclear medicine to diagnose and treat a variety of illnesses.

**Fast facts**

**Subject:** Chemistry, Biology
**Age range:** 16–18 years old
**Teacher preparation time:** 20 minutes
**Lesson time required:** 1 hour
**Location:** Classroom

### Pre-Lesson Preparation Activities

- Read through the teacher guide.
- Ensure access to computers/laptops.
- Print student worksheets.
- Check the link to the video (you may need to use Google Chrome or Microsoft Edge).
- Check the link to the virtual IonLab.

### Overview

Each year, tens of millions of lives are saved by nuclear medicine procedures which use radioactive isotopes (radioisotopes) to diagnose and treat a wide variety of illnesses like cancer, cardiovascular disease and brain disorders.

In this lesson, students will conduct a virtual column chromatography experiment to produce Yttrium-90 (90Y), an important radioisotope that can be used to treat liver cancer. Radioactive materials can be dangerous when handled improperly, and therefore this experiment must be conducted remotely.

Working in small groups, students will explore how other radioisotopes can be used in nuclear medicine, recognising the importance of selecting suitable chemical and radioactive properties for different applications.

1

TEACHER GUIDE

Nuclear Medicine: Chromatography in Action

### Materials & Equipment

- Computer and projector or smart screen for the teacher to display the PowerPoint and IonLab.
- Computers or other devices connected to the Internet for the students to conduct the IonLab Interactive Screen Experiment. One device needed for every 2-4 students (check the Internet browser is compatible with IonLab).
- Teacher handbook.
- Student worksheets (one per student).

### Lesson Plan

| Activity | Duration |
|---|---|
| 1. Welcome and lesson objectives | 5 |
| 2. Nuclear medicine animated video | 5 |
| 3. Introduce students to the IonLab experiment | 10 |
| 4. Start the IonLab experiment<br>(Note: the experiment takes ~30 mins to complete. Once set-up, continue going through the content but check on the experiment.) | 10 |
| 5. Check on the experiment – inject $^{90}Sr/^{90}Y$ solution into column | - |
| 6. Understanding the science behind the experiment | 10 |
| 7. Check on the experiment – change nitric acid concentration | - |
| 8. Medical radioisotopes – team task | 15 |
| 9. End of experiment - class discussion | 5 |
| **Total Duration** | 60 |

2

TEACHER GUIDE

Nuclear Medicine: Chromatography in Action

### Lesson Walk-through

**1. Welcome (Slides 1-2)**

If you are a STEM ambassador, give a brief introduction to yourself. Provide an overview of what the students will be doing in today's lesson and what the learning objectives are. Hand out the student worksheets which contain blanks for the students to fill in.

**2. Nuclear medicine introduction (Slide 3)**

Play the video, encourage students to fill in the blanks on page 1 of their worksheet:

- Nuclear Medicine: from half-lives to saving lives (3 minutes, 17 seconds) https://mymedia.leeds.ac.uk/Mediasite/Play/2bc82942738446aeaed60f3b520f33e91d
The link may need to be opened in Google Chrome or Microsoft Edge to work, if it still does not work, please try https://vimeo.com/649207531/80baf68305

**3. Introducing radioactive decay and column chromatography (Slides 4 - 8)**

***Slide 4:*** In today's lesson, students will be carrying out an experiment to separate Ytrrium-90 ($^{90}Y$) from Strontium-90 ($^{90}Sr$) using column chromatography. $^{90}Y$ is an important radioisotope that can be used to treat liver cancer using a procedure known as brachytherapy.

***Slide 5:*** $^{90}Y$ is formed when $^{90}Sr$ undergoes **radioactive beta minus decay (β-).** $^{90}Y$ also undergoes *β-* decay to form stable zirconium-90. Beta minus decay occurs when a radioisotope has too many neutrons. To reach a more stable state, one of the neutrons decays into a proton and an electron. The proton stays within the nucleus but the electron is emitted with a lot of energy.

***Slide 6:*** The half-life is the time required for the decaying isotope to fall to one half of it's initial quantity. *$^{90}Y$ has a short half-life of 64 hours, $^{90}Sr$ has a longer half-life of around 29 years, which isotope would you rather have in your body?* The short half-life of $^{90}Y$ means that it can be implanted in the cancer and deliver a high dose of radiation in a relatively short time period before being filtered by the kidneys and passed out as urine over a few days. $^{90}Sr$ would require a lot more material to deliver a similar radiation dose and can accumulate in bones where it would remain until it had decayed. It would continue to deliver a steady radiation dose which could lead to bone cancer and cancer of the surrounding tissues. It is therefore very important to be able to separate these two isotopes.

***Slide 7:*** *Ask the students if they have ever used chromatography before, if they have, what type and how does it work?* Chromatography provides an effective method of separating, purifying and identifying components in a mixture. All forms of chromatography work on a similar principle; they all have a stationary phase and a mobile phase. The mobile phase flows through the stationary phase and carries the components of the mixture with it.

***Slide 8:*** To separate $^{90}Y$ from $^{90}Sr$, we can use a form of column chromatography. Here, a glass column is packed with an absorbent material (stationary phase) and a solvent (mobile phase) is then added to cover the stationary phase and 'wet' the entire column. The mixture to be separated (e.g. radioactive solution) is then carefully added to the top of the column. The solvent is allowed to run through the column, slowly and

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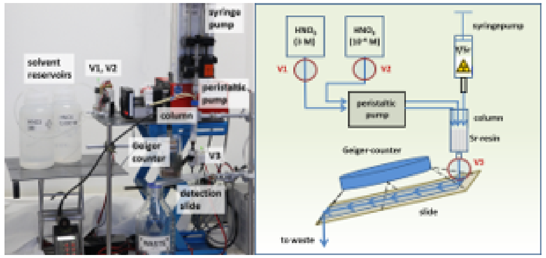
continually. It is important that the column never becomes dry otherwise it can affect the separation.

As the mobile phase runs though the column, the components of the mixture separate out as they move at different rates. This rate depends on how soluble each component is in the mobile phase and how strongly it is retained (adsorbed) by the stationary phase. Components that adsorb strongly to the stationary phase will take a long time to travel down the column. Components that are very soluble in the mobile phase will pass through the column quickly. Therefore, it's a trade-off between how much a component sticks to the surface versus how quickly it is washed through by the solvent.

**4. Start the experiment (Slide 9)**

Divide the class into groups of 2-4 students and give each group a device to access the IonLab experiment: http://ibe.irs.uni-hannover.de/ibes/de/RoboLabs/IonLab.html




Talk through the experimental set-up (as shown above). **Point out:** the two nitric acid solvents with different concentrations (mobile phase), the glass column packed with the resin (stationary phase), the syringe containing the mixture of $^{90}Sr/^{90}Y$, the slide that collects the output from the column, the Geiger counter.

Highlight that this experiment uses nitric acid ($HNO_3$) as the solvent but that there **are two concentrations** available. The order in which we add these solvents is important for selectively extracting $^{90}Y$ from the mixture of $^{90}Sr/^{90}Y$. Working as a class, students will determine the order in which to add the solvents **by asking one half of the class to start with 3M $HNO_3$, and the other half to start with 0.0001 M $HNO_3$** (step 4 in experimental procedure).

Whilst the students are preparing the column, **explain what is meant by the background count rate** – *"There is always a level of radiation around us, this is a measure of the local background radiation".* Point out the positioning of the Geiger counter above the slide to monitor the radiation of the solution, hence why the chromatogram uses counts per second (cps) on the y-axis versus time.

Tell the students to start the experiment and follow the instructions until step 13 in their worksheet pack. **Remind them to keep an eye on the time,** they may need to use a timer. Please see page seven of this guide for trouble shooting instructions.





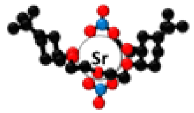


**5. Check on the experiment**

After five minutes, students should estimate the average background count rate by looking at the points on their data plot (these will be variation, just a rough average is fine). They should then click 'inject activity'. While students wait for the first peak to build, step 13, continue with the PowerPoint.

**6. Understanding the science behind the experiment (Slides 10 - 13)**

***Slide 10:*** Inside the column, there is a solid ion exchange resin which is the stationary phase. This resin is coated with a crown ether based ion exchange resin. A crown ether is an organic compound made up of carbon and oxygen atoms connected to form a ring. These compounds are known to be very selective towards certain elements, based on the size of the ring. In this experiment, the $Sr^{2+}$ cation is the perfect size to fit the diameter of the crown ether.




***Slide 11:*** However, the crown ether will only retain Sr in high nitric acid concentrations when there are enough nitrate ions in solution to form the stable complex shown above. The nitrate ions trap the Sr in the ring.

The retention factor ($R_f$) is a measure of the time the analyte component ($^{90}Y$ or $^{90}Sr$) resides in the stationary phase relative to the time it resides in the mobile phase. If the analyte resides mainly in the stationary phase, then $R_f$ is large. If the analyte resides in the mobile phase and moves quickly through the ion exchange resin, $R_f$ is small.

*Looking at the $R_f$ values for the different concentration of nitric acid and Sr/Y, which concentration will trap the $^{90}Sr$?* At a higher concentration of nitric acid, the $^{90}Sr$ has a high $R_f$ which means it is strongly absorbed by the stationary phase. At low concentrations (<0.01 M) both $^{90}Y$ or $^{90}Sr$ it will readily pass through the column.

***Slide 12:*** If we have a good separation, we should see two separate peaks. The first peak when $^{90}Y$ passes through, then the second peak when $^{90}Sr$ passes through. *Who thinks they will get this chromatogram?*

*Which order should we add the solvents to get two peaks?* By starting with 3 M $HNO_3$, the column should retain $^{90}Sr$ (high $R_f$) and allow $^{90}Y$ (low $R_f$) to pass through giving the first peak. When we change to 0.0001 M $HNO_3$, the column no longer retains $^{90}Sr$ so we should see a second peak appear.

***Slide 13:*** If we have a poor separation, both $^{90}Sr$ and $^{90}Y$ will pass out at the same time giving a singular peak. *Who thinks they will get this chromatogram?* If you started with 0.0001 M $HNO_3$, the $R_f$ is low for both species and therefore they both pass through the column at roughly the same rate. Only one peak will appear.

**7. Check on the experiment**

Students should check whether the first peak in their chromatogram has dropped back down to the background count rate and then change the concentration of the nitric acid. While they wait to see if the second peak will appear, continue with the medical radioisotopes team task.







**8. Medical radioisotopes - team task**

For the next activity, assign groups of students one of the medical radioisotopes from the list below:

- Technetium-99m (gamma emitter, $t_{1/2}$ = 6 hours, used for diagnosis)
- Iodine-131 (beta and gamma emitter, $t_{1/2}$ = 8 days, diagnose and treat cancers of the thyroid gland)
- Xenon-133 (beta and gamma emitter, $t_{1/2}$ = 5.2 days, study lung function)

Using their workbooks and the internet, the groups have 10 minutes to investigate how this radioisotope is used in nuclear medicine and record their findings on their worksheet. The aim of this exercise is to demonstrate the importance of half-life and radiation type in selecting a suitable radioisotope for medical applications $R_f$.

After 10 minutes of research, pair up the groups and get the students to share the results of their research with each other:

- Ask the students to describe their radioisotope, half-life, radiation type and its medical use.
- Ask the students to compare the different radioisotopes with each other and consider the importance of half-life and radiation type for medical applications.

**9. End of experiment – class discussion**

Ask the students to check if their second peak has been measured (if they started with 0.0001 M $HNO_3$, there should be no second peak). Click on 'logout and exit'.

Discuss with the class the following about the experiment:

- Is the chromatogram profile what they were expecting?
- What hazards are associated with this experiment, particularly if they were conducting a live nuclear experiment?
- How would you improve the design of the experiment?
- You can ask students to describe or draw a sketch of their chromatogram on the whiteboard.

**10. OPTIONAL IF THERE IS TIME**

Ask students to complete page four of the worksheet to check their understanding. This can also be completed after the lesson as a follow up if desired.

**OR** Explore a range of videos on nuclear careers on the A-CINCH Hub: https://www.cinch-project.eu/links

An additional lesson "Pyro-Processing: Electrochemical Cells in Action" can be found through the A-CINCH Wiki website: https://nucwik.com/exercises/ or by searching the STEM Learning Community website: https://community.stem.org.uk/

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TEACHER GUIDE

**Experiment Trouble Shooting**

- **The IonLab is not opening.** *Try using google chrome or Microsoft edge as your browser instead of internet explorer.*
- **No data points are being recorded on my data plot.** *Go onto the measurement tab and check that the measurement time is set to 2400 seconds and the counting interval to 10 seconds. Check that you have clicked "start measurement". If you have clicked "Reset Data" it will take a while to start filling again.*
- **I got a peak straight away instead of measuring the background count rate.** *You have probably clicked the "inject activity" button too soon. Restart the experiment by reloading the webpage, don't click "inject activity" until step 11.*
- **I have only got one peak.** *Don't worry! If you started with 0.0001 M $HNO_3$ from valve 2, there should be no second peak. You must use a strong concentration of nitric acid to retain the strontium in the column.*
- **I didn't get any peaks.** *You might have forgotten to click "inject activity", go back and check that you have followed all the instructions.*
- **My camera feed isn't working.** *You can try swapping browser to see if this fixes it, if not, the camera is not essential to the experiment and you can carry on without it.*
- **I don't know how to calculate the background count rate.** *The background count rate is a measure of the amount of background radiation in the local environment. To calculate the background count rate, after running the experiment for five minutes, look at the data points on the data plot and record the count rate (y-axis) that best represents most of the points.*

**Answers to Page 1:**

| | | | |
|---|---|---|---|
| (1) | Protons | (6) | Separate |
| (2) | Neutrons | (7) | Purify |
| (3) | Unstable | (8) | Identify |
| (4) | Time | (9) | Solubility |
| (5) | Half | (10) | Retention |



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STUDENT WORKBOOK
Nuclear Medicine

# Nuclear Medicine:
## Chromatography in Action

**Key Vocabulary – Fill in the blanks using information from the video & PowerPoint.**

**Isotopes**

Isotopes of an element have the same number of ___________ but a different number of ___________.

**Radioactive isotopes (radioisotope)**

A radioisotope is an isotope of an element that has an _____________ nucleus.

This causes them to undergo changes in the nucleus in a process known as radioactive decay. In doing so they emit radiation in the form of alpha, beta or gamma (α, β or γ) or a combination of them.

**Alpha particles (α)**

An alpha particle is made up of two protons and two neutrons, like a helium nucleus ( ${}^{4}_{2}He^{2+}$). Alpha particles are relatively slow and heavy; this means that they interact readily with matter and lose their energy very quickly, over a short distance. Alpha particles have little penetrating power and can easily be stopped by the first layer of skin.

**Beta minus decay (β-)**

Beta minus decay occurs when a radioisotope has too many neutrons. To reach a more stable state, one of the neutrons decays into a proton and an electron (conserving charge and mass/energy). The proton stays within the nucleus but the electron is emitted with a lot of energy. This high energy electron is more penetrating than alpha and can pass through the skin. However, it can be stopped by a thin sheet of aluminium (aluminium = 2,710 $kg/m^3$) as this is denser than human flesh (approximately 985 $kg/m^3$).

**Gamma (γ)**

Gamma rays represent energy in the form of an electromagnetic wave, the same as light but with a lot more energy. Gamma radiation is highly penetrating and can only be stopped by thick and/or dense materials, for example lead (11,343 kg/m3) or thick concrete (similar density to aluminium).

**Half-life ($t_{½}$)**

The _____________ required for the decaying quantity to fall to _____________ of its initial value.

**Column Chromatography**

Chromatography is a technique used to _______________, _______________ and ___________ components in a mixture.

The rate at which a substance travels through the column depends on its _______________ in the mobile phase and its _____________________ by the stationary phase.



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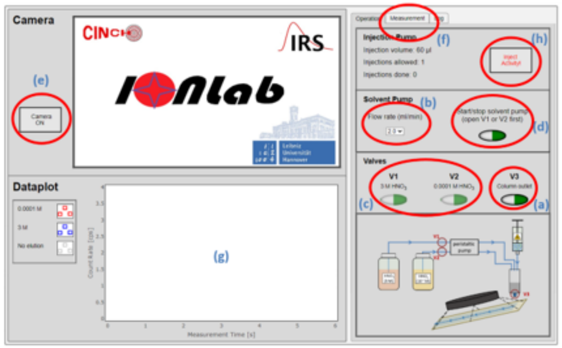
STUDENT WORKSHEET

..........................................................
Student name

## Experimental Procedure

**Open the virtual lab http://ibe.irs.uni-hannover.de/ibes/de/RoboLabs/IonLab.html**




**Prepare the column**

1. **DO NOT** click Inject Activity (h) until step 11!
2. Open valve 3 (a) to start the experiment.
3. Set the solvent flow rate (b) to 2 ml/minute.
4. Select either valve 1 or 2 (c), depending on which valve your teacher has asked you to start with, to add the solvent $HNO_3$. Record the valve here: Valve _____ with a concentration of ________ M.
5. Click on "start solvent pump" (d) to begin pumping the solvent onto the column. Use the camera feed (e) to check that the pump is rotating.
6. Set up your measurement parameters by going to the measurement tab (f). Set the measurement time to 2400 seconds and the counting interval to 10 seconds (this is how often the Geiger counter will record the activity). **Click on "start measurement".**
7. Allow the solvent to run for 5 minutes to wet the entire column. If you have extra time while waiting, start filling in page four of this worksheet.



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STUDENT WORKSHEET

Student name

**Separation of $^{90}Y$ from $^{90}Sr$**

9. After 5 minutes, estimate the average background count rate by looking at your Data Plot (g) and writing down the count rate that best represents most of your data points __________.
10. Stop the solvent pump (d).
11. Click on "inject activity" (h). The syringe will administer the $^{90}Sr/^{90}Y$ solution into the top of the column.
12. Start the solvent pump (d). Check that the measurement table is being filled.
13. Allow the first peak in the chromatogram on your data plot to build up. Let your teacher know you are ready to find out more about the experiment.
14. Once your first peak has returned to the background count rate, it is time to swap solvent concentrations. If you selected valve 1 in step 4, open valve 2 now or vice versa. Record the valve here: Valve _____ with a concentration of ________ M.
15. Allow the second peak to build up and return to the background count rate. While you wait for the peak to build, continue with the medical radioisotopes task on the next page.
16. After the second peak has been recorded, if there is one, the experiment is complete. If you would like to, you can email the data and logbook to your school email address. Click on 'logout and exit'.

**Observations**

Draw and label a sketch of what you expect your chromatogram to look like.

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STUDENT WORKSHEET

Student name

**Test Your Understanding**

Q. Calculate the number of protons, neutrons and electrons for the isotopes of potassium.

| | $^{39}K$ | $^{40}K$ | $^{41}K$ |
|---|---|---|---|
| Protons | | | |
| Neutrons | | | |
| Electrons | | | |

Q. Calculate how many protons, neutrons and electrons there are in $^{90}Sr$, $^{90}Y$ and $^{90}Zr$.

| | $^{90}Sr$ | $^{90}Y$ | $^{90}Zr$ |
|---|---|---|---|
| Protons | 38 | | |
| Neutrons | 52 | | |
| Electrons | 38 | | |

Q. In your experiment, which component is the mobile phase? Which is the stationary phase?

Q. Why is it important to wet the column at the start of the experiment?

Q. What is the correct order for adding the solvents and why?

Q. What is the problem with storing $^{90}Y$ for too long before using it?

Q. What does the retention factor ($R_f$) describe?

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STUDENT WORKSHEET

Name

**Medical Radioisotopes – properties and applications**

Which medical radioisotope are you investigating?

What is its half-life?

What type of radiation does it emit?

How is it produced?

What is it used for?

Describe at least one benefit and one disadvantage of this procedure:

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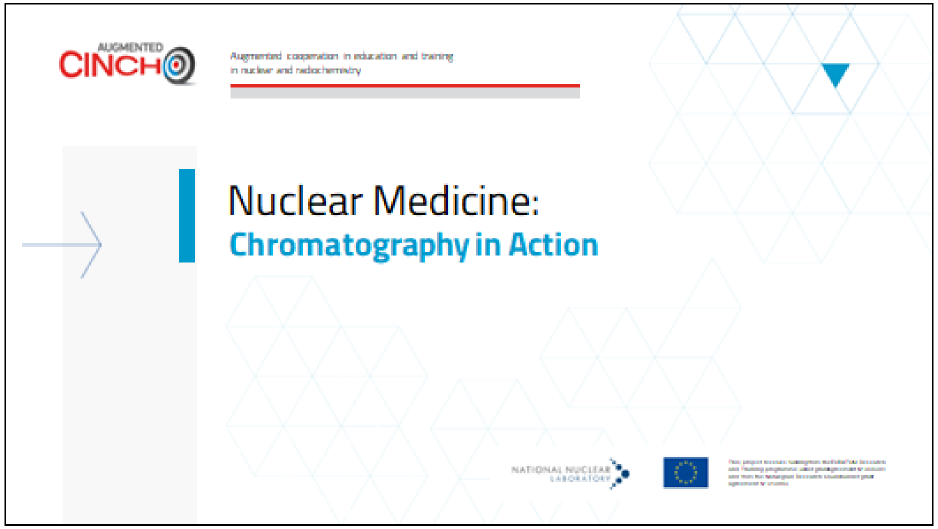
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Nuclear Medicine:
Chromatography in Action
NATIONAL NUCLEAR LABORATORY

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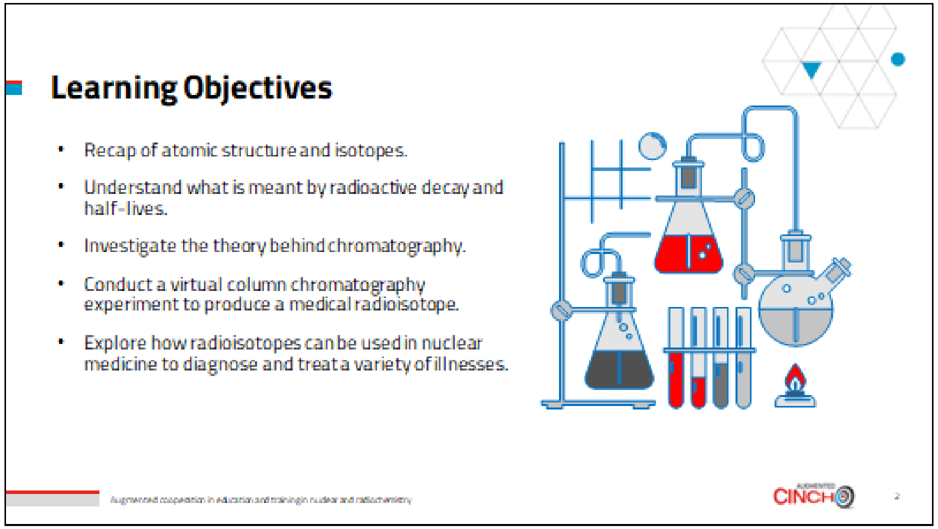
Learning Objectives
• Recap of atomic structure and isotopes.
• Understand what is meant by radioactive decay and half-lives.
• Investigate the theory behind chromatography.
• Conduct a virtual column chromatography experiment to produce a medical radioisotope.
• Explore how radioisotopes can be used in nuclear medicine to diagnose and treat a variety of illnesses.
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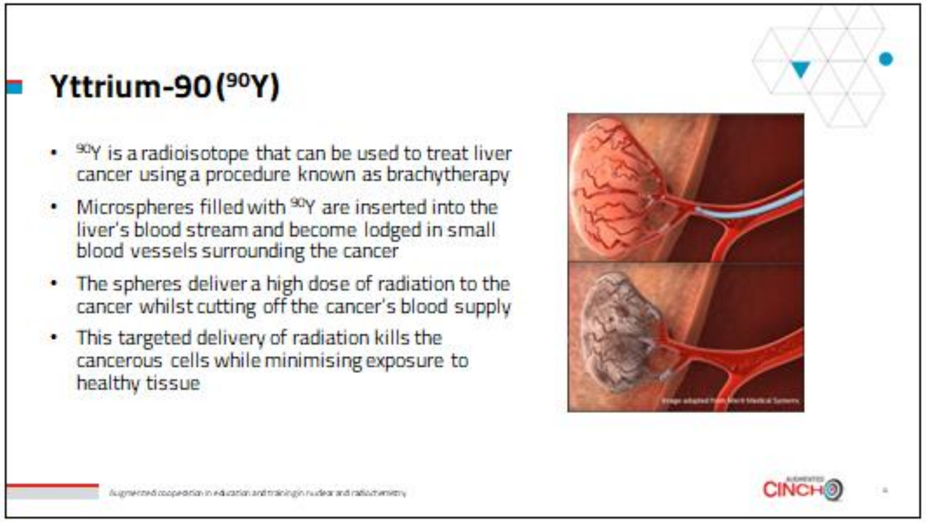
2


Introductory Video
MEDICAL RADIOISOTOPES
https://vimeo.com/649207531/80baf68305
Augmented cooperation in education and training in nuclear and radiochemistry
CINCH

3


Yttrium-90 ($^{90}Y$)
• $^{90}Y$ is a radioisotope that can be used to treat liver cancer using a procedure known as brachytherapy
• Microspheres filled with $^{90}Y$ are inserted into the liver's blood stream and become lodged in small blood vessels surrounding the cancer
• The spheres deliver a high dose of radiation to the cancer whilst cutting off the cancer's blood supply
• This targeted delivery of radiation kills the cancerous cells while minimising exposure to healthy tissue
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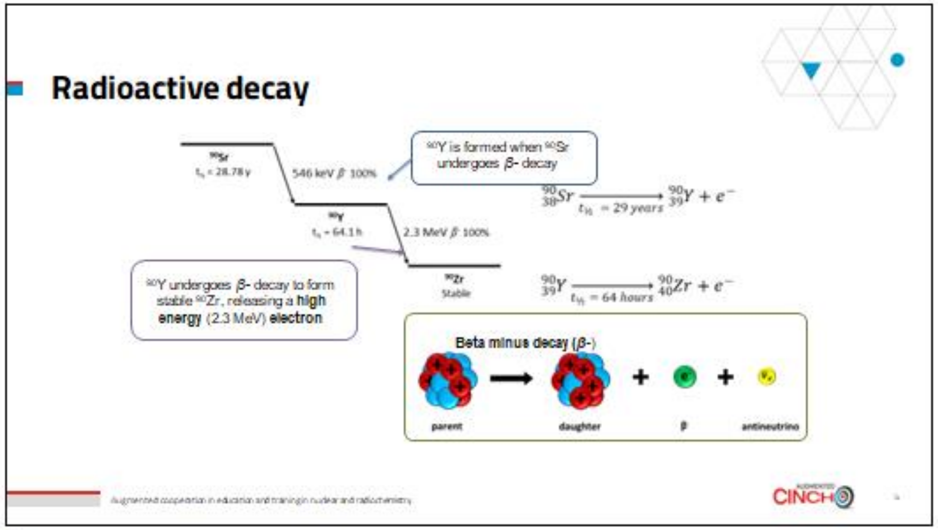
4


Radioactive decay
$^{90}$Y is formed when $^{90}$Sr undergoes β- decay
$^{90}_{38}Sr \xrightarrow{t_{½} = 29\ years} {}^{90}_{39}Y + e^-$
546 keV β 100%
2.3 MeV β 100%
$^{90}$Zr Stable
$^{90}$Y undergoes β- decay to form stable $^{90}$Zr, releasing a high energy (2.3 MeV) electron
$^{90}_{39}Y \xrightarrow{t_{½} = 64\ hours} {}^{90}_{40}Zr + e^-$
Beta minus decay (β-)
parent
daughter
β
antineutrino
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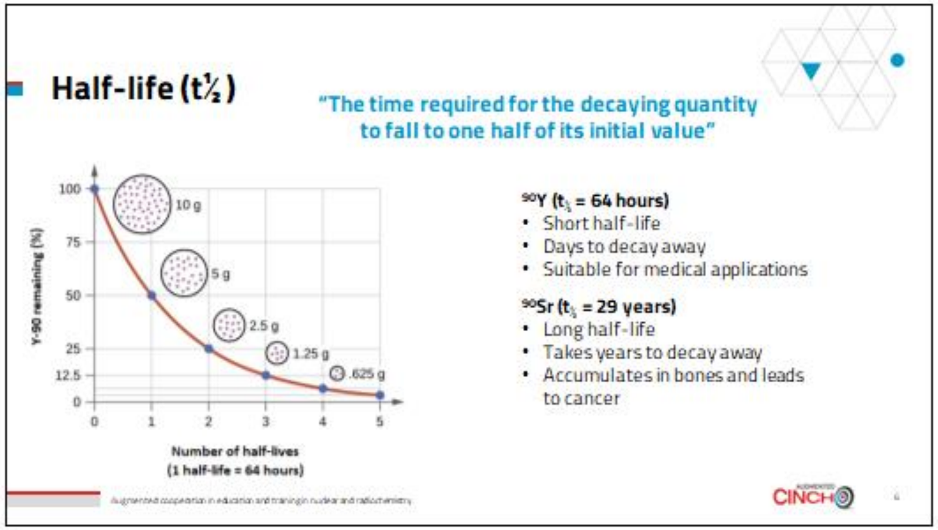
Half-life (t½)
"The time required for the decaying quantity to fall to one half of its initial value"
Y-90 remaining (%)
100
75
50
25
12.5
0
10 g
5 g
2.5 g
1.25 g
.625 g
0 1 2 3 4 5
Number of half-lives
(1 half-life = 64 hours)
$^{90}$Y ($t_{½}$ = 64 hours)
• Short half-life
• Days to decay away
• Suitable for medical applications
$^{90}$Sr ($t_{½}$ = 29 years)
• Long half-life
• Takes years to decay away
• Accumulates in bones and leads to cancer
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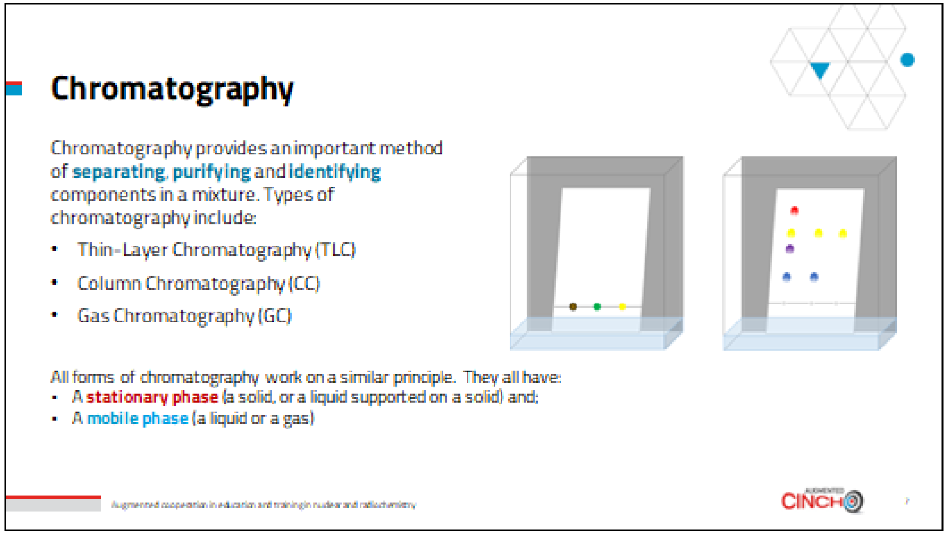
Chromatography
Chromatography provides an important method of separating, purifying and identifying components in a mixture. Types of chromatography include:
• Thin-Layer Chromatography (TLC)
• Column Chromatography (CC)
• Gas Chromatography (GC)
All forms of chromatography work on a similar principle. They all have:
• A stationary phase (a solid, or a liquid supported on a solid) and;
• A mobile phase (a liquid or a gas)
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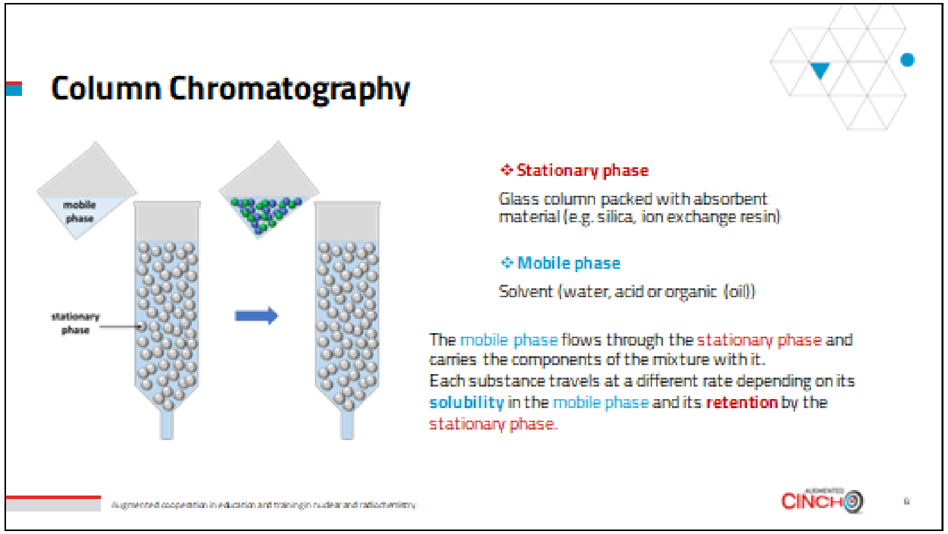
Column Chromatography
mobile phase
stationary phase
❖ Stationary phase
Glass column packed with absorbent material (e.g. silica, ion exchange resin)
❖ Mobile phase
Solvent (water, acid or organic (oil))
The mobile phase flows through the stationary phase and carries the components of the mixture with it.
Each substance travels at a different rate depending on its solubility in the mobile phase and its retention by the stationary phase.
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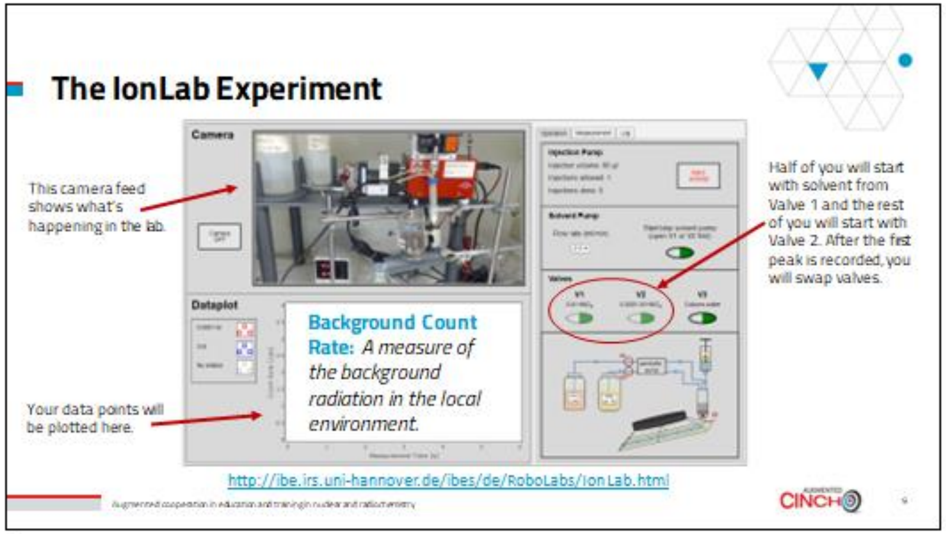
The IonLab Experiment
Camera
Dataplot
This camera feed shows what's happening in the lab.
Your data points will be plotted here.
Background Count Rate: A measure of the background radiation in the local environment.
Half of you will start with solvent from Valve 1 and the rest of you will start with Valve 2. After the first peak is recorded, you will swap valves.
http://ibe.irs.uni-hannover.de/ibes/de/RoboLabs/IonLab.html
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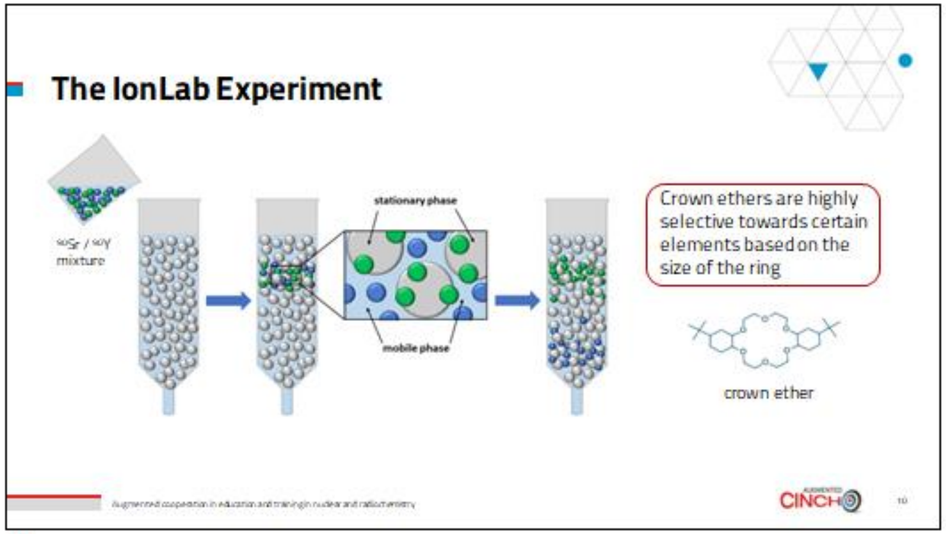
The IonLab Experiment
$^{90}Sr$ / $^{90}Y$ mixture
stationary phase
mobile phase
Crown ethers are highly selective towards certain elements based on the size of the ring
crown ether
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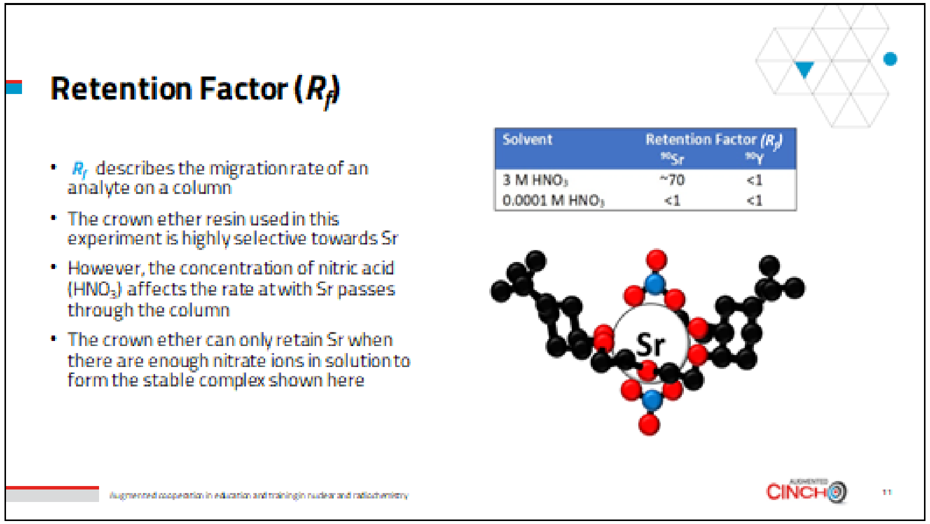
Retention Factor ($R_f$)
$R_f$ describes the migration rate of an analyte on a column
The crown ether resin used in this experiment is highly selective towards Sr
However, the concentration of nitric acid ($HNO_3$) affects the rate at with Sr passes through the column
The crown ether can only retain Sr when there are enough nitrate ions in solution to form the stable complex shown here
Solvent | Retention Factor ($R_f$) $^{90}Sr$ | $^{90}Y$
3 M $HNO_3$ | ~70 | <1
0.0001 M $HNO_3$ | <1 | <1
Sr
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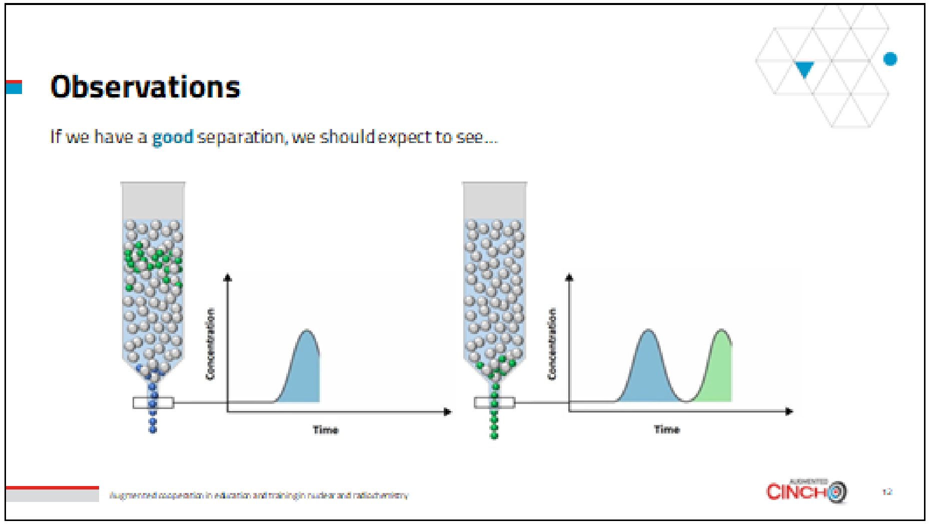
Observations
If we have a good separation, we should expect to see…
Concentration
Time
Concentration
Time
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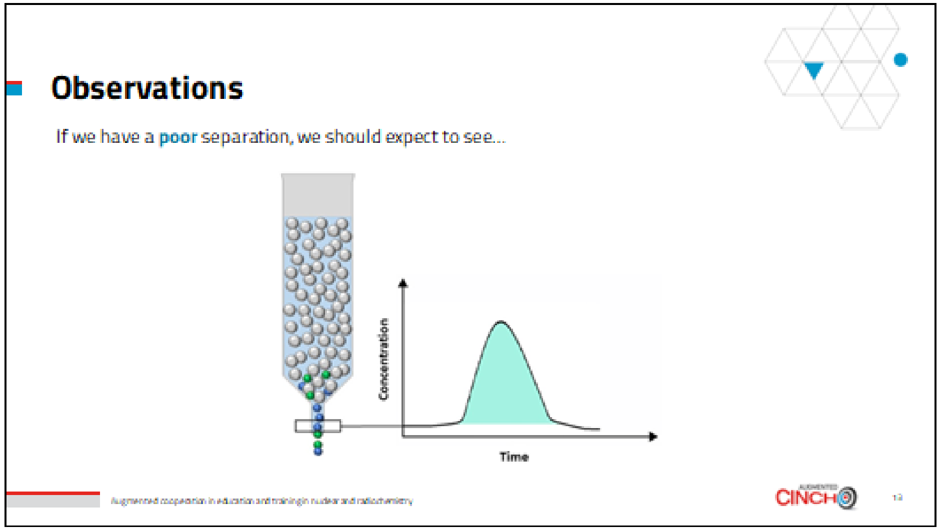
Observations
If we have a poor separation, we should expect to see...
Concentration
Time

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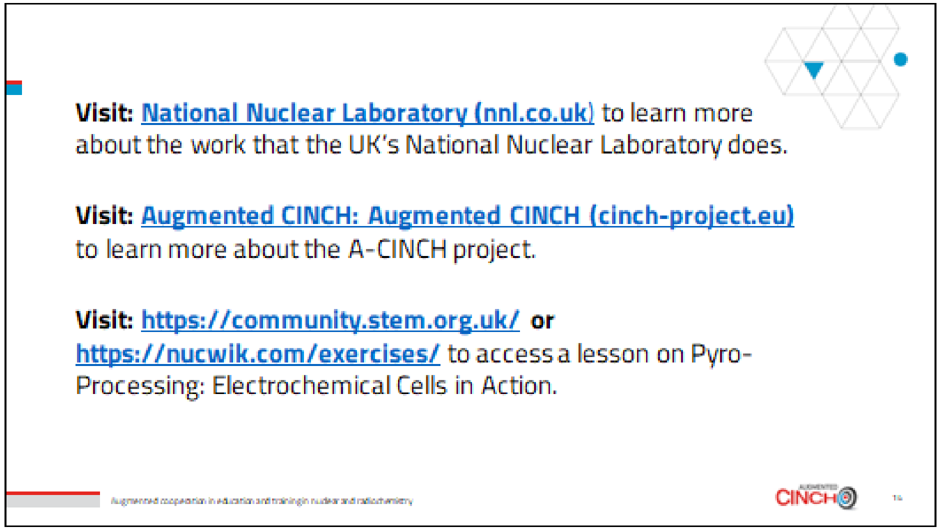
Visit: National Nuclear Laboratory (nnl.co.uk) to learn more about the work that the UK's National Nuclear Laboratory does.
Visit: Augmented CINCH: Augmented CINCH (cinch-project.eu) to learn more about the A-CINCH project.
Visit: https://community.stem.org.uk/ or https://nucwik.com/exercises/ to access a lesson on Pyro-Processing: Electrochemical Cells in Action.

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