AUGMENTED CINCH

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DELIVERABLE D5.8

Outreach toolkit

Lead Beneficiary: NNL

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CO	Confidential, only for Beneficiaries of the A-CINCH project	

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1.3	16/11/2023	Mojmír Němec	Coordinator's check and approval

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EXECUTIVE SUMMARY

The purpose of this report is to summarise activities related to the delivery of the 'Lab in a box' task and its evaluation. The aim of this work package was to develop off the shelf outreach activities that can be used by institutions to promote nuclear and radiochemistry at schools, colleges or science fairs. Nine different activities have been developed, tested, improved and then finalised.

The nine activities are: Bright salt: Structural energy; Oder of radioactivity: Radiation around us; For your glove: Nuclear contamination demonstration; Nuclear energy: I'm in the middle of a (nuclear) chain reaction; Radioactive nuclei: Decay and half-life demonstration; Imposter: Keeping nuclear Materials Safe; Nuclear medicine: Separating Radionuclides; RADiation robots: Handling nuclear waste and Think inside the box: Glove box handling techniques.

Over 800 students have used the materials produced at three separate science festivals: All Together Cumbria's Festival of Work, IET's Engineering Open House Week and Humber Science Festival. The kits are also scheduled to be used at three more upcoming science festivals. Positive feedback has been received from each science festival; the main highlight being how easy the kits are to use and how engaged the students are.

The Lab in a Box packages have been designed so that each activity can be delivered independently by any teacher/STEM ambassador, using only the risk assessment and STEM ambassador guides that are found online, and the resources required can be easily acquired and purchased. The risk assessments, STEM ambassador guides and any other support information has been uploaded to CINCH Hub, NNL's Outreach database, Women In Nuclear's outreach database and to the STEM Community website to allow public access and use of the resources.

CONTENT

1 INTRODUCTION

Nine different lab in a box activities have been developed for students aged between 5 – 18. The lab in boxes have been designed as ‘hands on’ activities that cover a range of different topics in the nuclear industry. The materials needed to deliver all the activities are cheap and easy to acquire.

1.1 Development of Lab in Box Packages

In previous A-CINCH meetings it was identified attendance at science festivals and careers fairs is a very popular and successful way to raise awareness of an area of science, but for obvious reasons this is challenging in the area of nuclear radio chemistry. The focus of this work package was to create ‘off the shelf’ outreach activities that can be used by institutions to promote nuclear and radiochemistry at science festivals or within the classroom.

Each pack includes a STEM ambassador guide, a risk assessment and some packs include supporting material as required. The STEM ambassador guides include: the objectives of the activity, an overview, age range, preparation and demonstration time, an equipment list and links to purchase the items, background information and the demonstration procedure. The risk assessment is a generic risk assessment format that can be submitted to any science fair to make organization for the STEM ambassador easier.

After research into the different science festivals and STEM events it was found that there are two main formats: The first is where the STEM ambassadors have a stall and students (sometimes with their parents) come along to the stand, engage with the STEM ambassador and activities, then move into the next stall; the second format is when the STEM ambassadors deliver a session to a class of students, typically 3. The ambassadors then deliver multiple sessions to fill a designated amount of time, then a new group of students arrives. The nine activities have been developed so that there are multiple options that cater for both styles of science festival.

1.1.1 Bright salt: Structural energy

This activity visualizes the fluorescence of a chemical in an excited state as it returns to its ground state, following its irradiation in a nuclear reactor. There is a follow up activity where it is explored how thermal fluorescence can be used in the nuclear industry to diagnose and monitor radiation exposure.

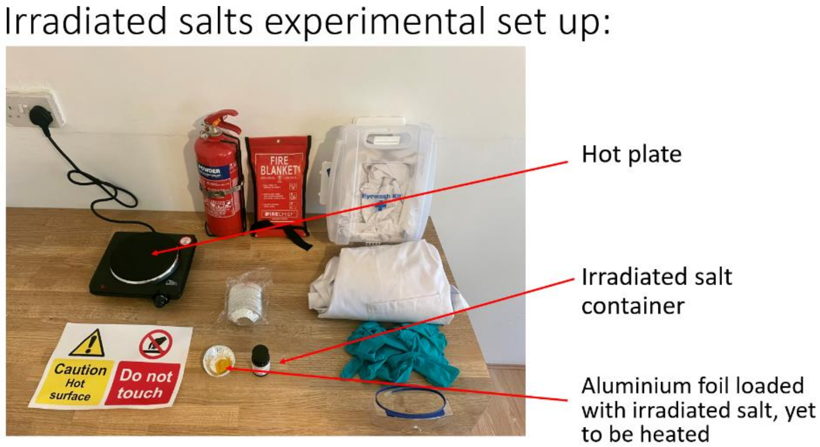


Figure 1. 1.1.1 Bright salt: Structural energy experimental set up

1.1.2 Order of radioactivity: Radiation around us

This activity is designed for the students to understand that radiation can be found in nature as well as in many other aspects of our lives, such as fire alarms and airplane travel. The students order the items from what they think is the most radioactive to the least radioactive. The STEM ambassador can then have discussions with the student over why and how each object is radioactive.

Figure 2. Order of radioactivity: Radiation around demonstation

1.1.3 For your glove: Nuclear contamination demonstration

This activity is designed to introduce students to methods that radiochemists use to keep themselves safe when handling radioactive materials. The STEM ambassador demonstrates a glove change, the student then attempts to copy this. The gloves are sprinkled with UV powder, if any of these transfers onto the student hands then they would have contaminated themselves!

Figure 3. For your glove: Nuclear contamination demonstration

1.1.4 Nuclear energy: I’m in the middle of a (nuclear) chain reaction

This activity introduces students to the concept of a chain reaction- a fission reaction. In the demonstration each student is an atom and they each have two balloons. One student throws their balloons into the air, if you are hit with one of the balloons then throw the two balloons you are holding. This continues until all the balloons have been thrown, demonstrating an uncontrolled fission rection. The activity in then repeated but with some ‘moderators’, these people grab balloons as they are thrown, slowing down the reaction. This is an example of a moderated fission reaction.

Figure 4. Nuclear energy: I’m in the middle of a (nuclear) chain reaction

1.1.5 Radioactive nuclei: Decay and half life demonstration

This activity introduces the concept of radioactive decay and half lives. Each student has a box with a circle inside, a cup filled with same skittles and a printed table to fill in. The student tips the skittles into the box, closes the box and gives it a shake, then opens the box. They then remove all the skittles wihtin the black circle, counting how many there removed. They then write this number in their table and reperat this process 10 times. They can then work our the half life of their skittles.

There is an optional extension activity, where the activity is repeated using circles of different sizes. They should find that if they are using a bigger circle the decay is faster and the half-life they calculate is shorter, and the reverse if using a smaller circle.

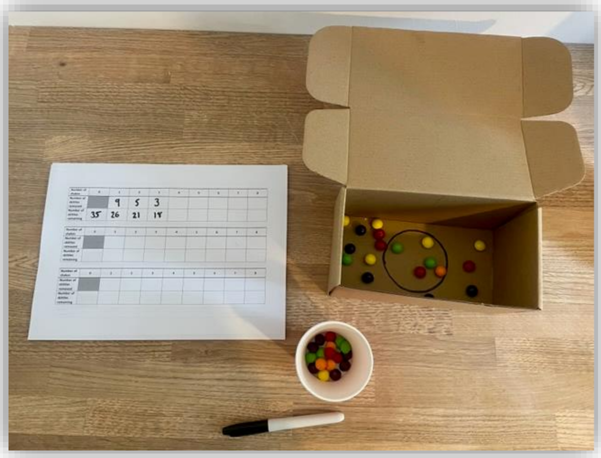


Figure 5. Radioactive nuclei: Decay and half life demonstration

1.1.6 Imposter: Keeping nuclear Materials Safe

This activity is to raise awareness of nuclear security, safeguards and non-proliferation. In order for society to beneifit from nuclear science and technology it is imperitive we keep our materials, sites and people safe and secure and this area of nuclear offers many varied careers.

The game is a team memory game. The students are spilt into teams of 4-10. Each team has a board and a pack of periodic table cards. The aim of the game is to recreate the center board, below in figure 6. The students take it in turns to walk up to the demonstation board and try their best to memorise it and recreate it on their team's board. But there will be an imposter in the group, they will be trying to sabotage the team's effort without getting caught.

Figure 6. Imposter: Keeping nuclear Materials Safe demonstration

1.1.7 Nuclear medicine: Separating Radionuclides

This activity introduces students to health and nuclear medicine; how radioactive molecules are used for medical diagnosis and cancer treatments. The demonstation imitates a separations column, used to separate medicinal radioisotopes from radioactive sludge for application in hospitals.

Figure 7. Nuclear medicine: Separating Radionuclides

1.1.8 RADiation robots: Handling nuclear waste

This activity introduces students to the role robotics and master slave manipulators (MSMs) play in the nuclear industry, particuarly in the area of cleaning up legacy nuclear waste. The student will use the arm to remove the wooden shapes from the basket of 'mixed radioactive waste' and isolate it, into the empty basket. This is to demonstrate separating different types of radioactive waste before they go onto to be treated and eventually disposed of. Here the grabber is representing a Master Stave Manipulators (MSMs).

Figure 8. RADiation robots: Handling nuclear waste demonstration

1.1.9 Think inside the box: Glove box handling techniques

This activity introdues students to glove boxes and how they are used by nuclear chemists. The actiity involes an imitation glove box, pictured below. The student will use the glove box to mix two different coloured solutions togther to create a third colour, using pasteur pipettes.

Figure 9. Think inside the box: Glove box handling techniques

2 ACTIVITY TRIALS, FEEDBACK AND FUTURE USE.

2.1 Activity Trials

Table 1 Science fairs Lab in a box activities have been trialed at:

Activity	Science fair(s) attended	Estimated no. of students engaged
Bright salt: Structural energy	IET Engineering Open House Week (Save the Date! 17 June 2023 #IETOpenHouse)	120
Oder of radioactivity: Radiation around us.	IET Engineering Open House Week (Save the Date! 17 June 2023 #IETOpenHouse); All Together CUMBRIA; Humber Science Festival	810
For your glove: Nuclear contamination demonstration	Humber Science Festival; All Together CUMBRIA; IET Engineering Open House Week (Save the Date! 17 June 2023 #IETOpenHouse)	810
Nuclear energy: I'm in the middle of a (nuclear) chain reaction	All Together CUMBRIA	90
Radioactive nuclei: Decay and half life demonstration	All Together CUMBRIA	90
Imposter Keeping nuclear Materials Safe	All Together CUMBRIA	90
Nuclear medicine: Separating Radionuclides	All Together CUMBRIA	90
RADiation robots: Handling nuclear waste	Humber Science Festival	600

Think inside the box: Glove box handling techniques	Humber Science Festival	600

2.2 Improvements made after Trials

Bright salt: Structural energy. On trialing this activity, it was encountered that the flash from the bright salt was difficult to see. ‘Tips’ were added to the method section in the STEM ambassador guide, including: ‘the darker the room the better to observe the sparkle’ and ‘You may want to do this for small groups of students so that they can get close enough to the hot plate to observe the small flashes of light’.

Oder of radioactivity: Radiation around us. To make this activity more accessible an image pack was created. The STEM ambassador guide was updated to include an image pack, which can be used instead of, or in conjunction, with the physical items in the activity.

For your glove: Nuclear contamination demonstration. On trialing this activity, it was found the UV powder fell over the demonstration table. Wet wipes were added to the kits to aid the clean-up process and effectively remove the UV powder from the table.

Nuclear energy: I’m in the middle of a (nuclear) chain reaction. This worked very well the first time and no significant changed were made.

Radioactive nuclei: Decay and half-life demonstration. After trialing this activity, it was found that drawing of the half-life table took the students a lot of time, as a result the activity became rushed. A template was created that can be printed and handed out to the students.

Imposter Keeping nuclear Materials Safe. On trailing this activity, it was found to work best for group sizes between 4 and 10. The instructions were updated to include this information. An extra unit of materials (a pack of cards and a cork board) were added to the box so that classes of 30 students could now be split into 3 groups.

Nuclear medicine: Separating Radionuclides. On trialing this activity, it was found that removal of the cotton wool balls from inside the columns at the end of the demonstration was difficult, tweezers were added to the equipment list to help with removal.

RADiation robots: Handling nuclear waste. This demonstration originally included an electronic remotely controlled robot arm to compare to the MSMs. This arm was found to be expensive, difficult to construct and delicate. The robot arm was removed and the activity was more successful without it.

Think inside the box: Glove box handling techniques. On trialing the activity, the glove box itself was very easy to move and it knocked over the glassware inside. Duct tape was added to stick the box to the table and prevent it slipping.

2.3 Use of Resources after A-CINCH

Sustainability was a key aspect of this task, especially the storage and distribution of activities. To deal with this, each lab in a box activity starts as a guide online which provides background about the activity, a list of components / equipment which are affordable and easy to procure.

Each activity has been designed so that they can be delivered independently by STEM ambassadors using only the STEM ambassador guide and the risk assessment, which they will be able to find online.

The STEM ambassador guides, risk assessments and any other supporting documents have been unloaded to: NNL:'s internal outreach database, STEM Ambassador's outreach database and they have been uploaded to UK Women in Nuclear's (WiN) outreach database. These are all forums for STEM educators where resources are openly shared.

Through these communities the kits are scheduled to be used at four upcoming events: WiN science fair Oxford, Fitzharrys Secondary School STEM fair, Keswick Secondary School's Careers Day and UlverSTEM festival. It is hoped to maintain/build on this momentum through continued active engagement with these STEM outreach communities.

2.4 Feedback

Overall great feedback was received for all nine activities including:

"The NNL team has set the gold standard for some of the best science activities I've seen, it would be my pleasure to collaborate more in the future." feedback on the NNL/A-CINCH stand at the engineering Open House Event

"It was great to see the students so engaged" feedback from a teacher at Whitehaven Academy during the Cumbria Festival of work.

"I had no idea things were naturally radioactive" and *"I never realised people did this for a job"* were both pieces of feedback received at the Humber Science Festival as well as many students asking about different pathways into the nuclear sector, such as apprenticeships and graduate programs.

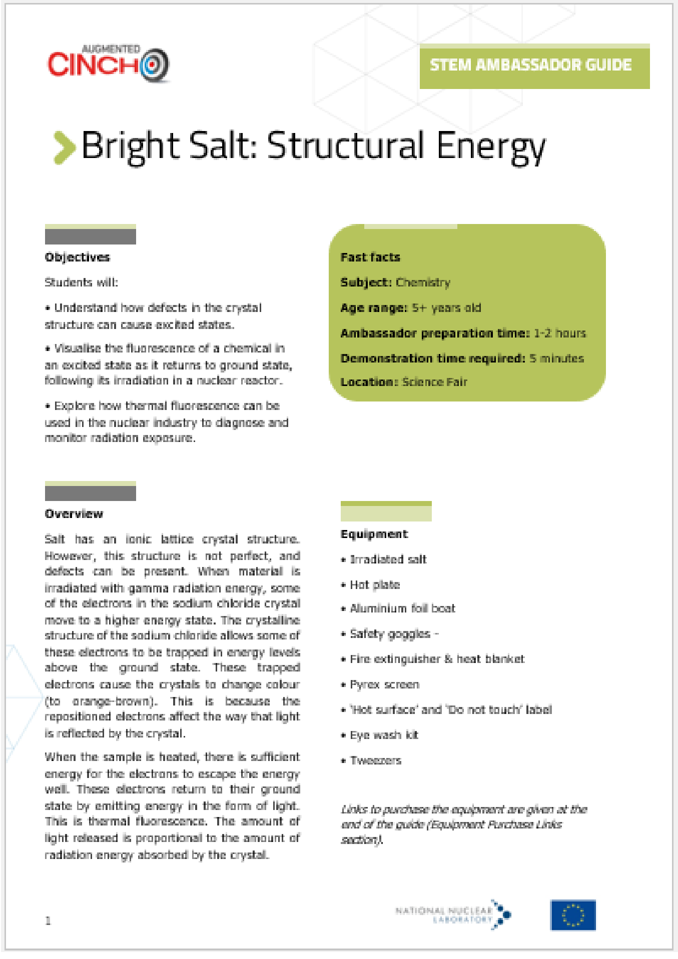
3 CONCLUSIONS

Nine lab-in-a-box activities have been developed trialed, tested and improved. Throughout demonstrations at STEM events an audience of over 800 pupils has been reached. Overall, positive feedback was received from students, teachers and STEM ambassadors. Comments from students and teachers reflected positively that the lab in boxes were excellent resources to raise awareness of the many different areas of the nuclear industry and the different jobs and career paths these offer.

The activities have been successfully carried out by STEM ambassadors, using only the online resources. It was fed back that this was easy to do and they would happily do it again in future. The resources have been uploaded to NNLs Outreach database, the STEM Community website and to Women In Nuclear's outreach database to allow for future use of the resources by the STEM outreach community.

ANNEXES

Annex I: Bright Salt: Structural Energy STEM Ambassador Guide.



STEM AMBASSADOR GUIDE

Bright Salt: Structural Energy

Objectives

Students will:

- Understand how defects in the crystal structure can cause excited states.
- Visualise the fluorescence of a chemical in an excited state as it returns to ground state, following its irradiation in a nuclear reactor.
- Explore how thermal fluorescence can be used in the nuclear industry to diagnose and monitor radiation exposure.

Fast facts

Subject: Chemistry

Age range: 5+ years old

Ambassador preparation time: 1-2 hours

Demonstration time required: 5 minutes

Location: Science Fair

Overview

Salt has an ionic lattice crystal structure. However, this structure is not perfect, and defects can be present. When material is irradiated with gamma radiation energy, some of the electrons in the sodium chloride crystal move to a higher energy state. The crystalline structure of the sodium chloride allows some of these electrons to be trapped in energy levels above the ground state. These trapped electrons cause the crystals to change colour (to orange-brown). This is because the repositioned electrons affect the way that light is reflected by the crystal.

When the sample is heated, there is sufficient energy for the electrons to escape the energy well. These electrons return to their ground state by emitting energy in the form of light. This is thermal fluorescence. The amount of light released is proportional to the amount of radiation energy absorbed by the crystal.

Equipment

- Irradiated salt
- Hot plate
- Aluminium foil boat
- Safety goggles -
- Fire extinguisher & heat blanket
- Pyrex screen
- 'Hot surface' and 'Do not touch' label
- Eye wash kit
- Tweezers

Links to purchase the equipment are given at the end of the guide (Equipment Purchase Links section).

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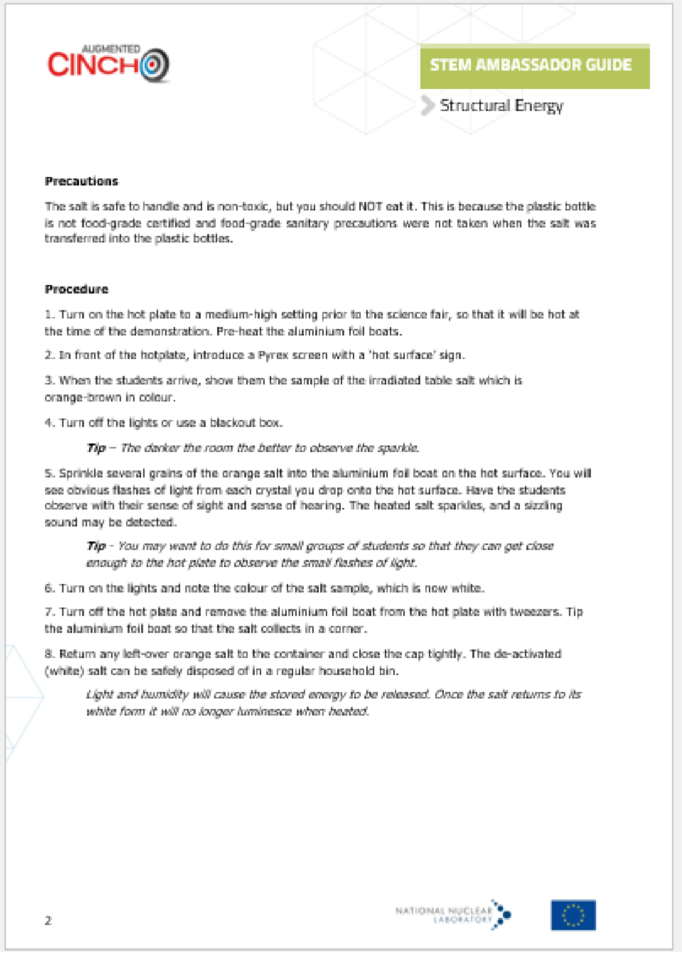

STEM AMBASSADOR GUIDE

Structural Energy

Precautions

The salt is safe to handle and is non-toxic, but you should NOT eat it. This is because the plastic bottle is not food-grade certified and food-grade sanitary precautions were not taken when the salt was transferred into the plastic bottles.

Procedure

1. Turn on the hot plate to a medium-high setting prior to the science fair, so that it will be hot at the time of the demonstration. Pre-heat the aluminium foil boats.

2. In front of the hotplate, introduce a Pyrex screen with a 'hot surface' sign.

3. When the students arrive, show them the sample of the irradiated table salt which is orange-brown in colour.

4. Turn off the lights or use a blackout box.

__Tip__ – The darker the room the better to observe the sparkle.

5. Sprinkle several grains of the orange salt into the aluminium foil boat on the hot surface. You will see obvious flashes of light from each crystal you drop onto the hot surface. Have the students observe with their sense of sight and sense of hearing. The heated salt sparkles, and a sizzling sound may be detected.

__Tip__ - You may want to do this for small groups of students so that they can get close enough to the hot plate to observe the small flashes of light.

6. Turn on the lights and note the colour of the salt sample, which is now white.

7. Turn off the hot plate and remove the aluminium foil boat from the hot plate with tweezers. Tip the aluminium foil boat so that the salt collects in a corner.

8. Return any left-over orange salt to the container and close the cap tightly. The de-activated (white) salt can be safely disposed of in a regular household bin.

Light and humidity will cause the stored energy to be released. Once the salt returns to its white form it will no longer luminesce when heated.

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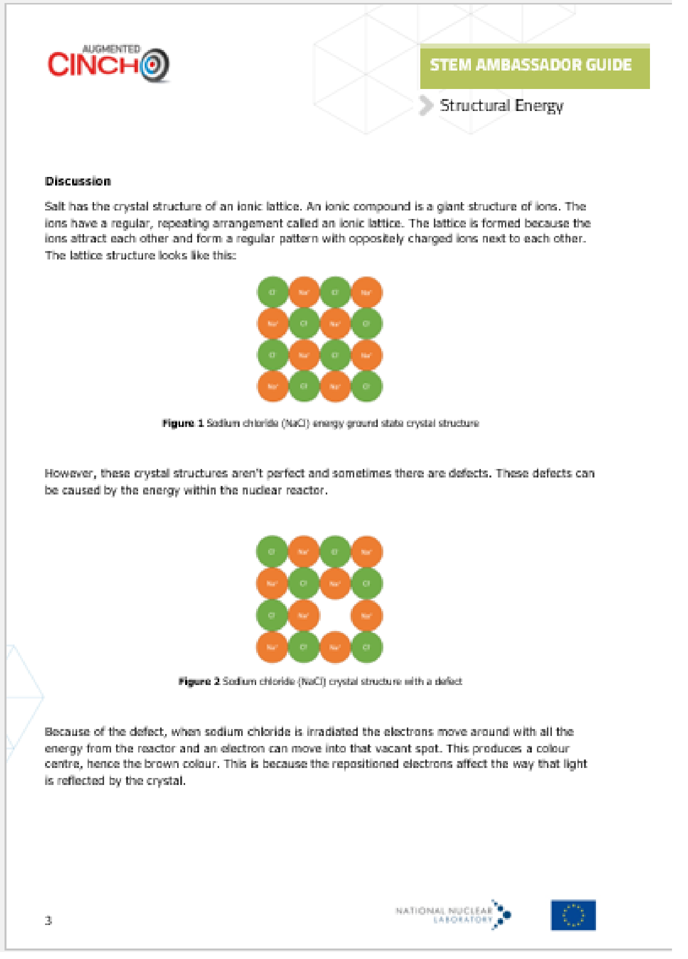

STEM AMBASSADOR GUIDE

Structural Energy

Discussion

Salt has the crystal structure of an ionic lattice. An ionic compound is a giant structure of ions. The ions have a regular, repeating arrangement called an ionic lattice. The lattice is formed because the ions attract each other and form a regular pattern with oppositely charged ions next to each other. The lattice structure looks like this:

Figure 1 Sodium chloride (NaCl) energy ground state crystal structure

However, these crystal structures aren't perfect and sometimes there are defects. These defects can be caused by the energy within the nuclear reactor.

Figure 2 Sodium chloride (NaCl) crystal structure with a defect

Because of the defect, when sodium chloride is irradiated the electrons move around with all the energy from the reactor and an electron can move into that vacant spot. This produces a colour centre, hence the brown colour. This is because the repositioned electrons affect the way that light is reflected by the crystal.

3

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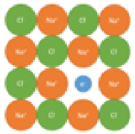

Figure 3 Sodium chloride (NaCl) energy excited state crystal structure

However, when you apply heat, you see thermo-luminescence and a colour change. This is because when the crystals are heated, the heat energy raises the trapped electrons to an even higher energy state where they are free to drop down to the ground state. As the trapped electrons are freed, their excess energy is released in the form of visible light. This phenomenon is called thermoluminescence, or thermal fluorescence. The amount of light released is proportional to the amount of radiation energy absorbed by the crystal. The heating also decreases the rigidity of the crystal lattice, allowing the salt crystals to revert to their original, defect-free state, which is white in colour. The salt is not radioactive.

Real-World Application

The concepts involved in this demonstration can be related to devices used to detect radiation exposure.

Radiation workers wear film badges called TLDs (Thermoluminescent dosimeters). Gamma rays that hit the badge are stored as energy in the badge. The badge uses a lithium fluoride (LiF) film (rather than sodium chloride, although the elements are in the same periodic groups, meaning they'll have the same physical and hence structural properties), which "stores energy" when exposed to ionizing radiation.

After a set period of time the nuclear worker will change their badge. The used badge is heated to release its stored energy and the amount of energy that is released is measured with a light-sensitive instrument (e.g., a photomultiplier tube). The amount of light released corresponds to the energy that was deposited in the lithium fluoride salt as the ionizing radiation passed through the material. The radiation dose received by the radiation worker can therefore be calculated.

Figure 4 Image of a TLD (Thermoluminescent dosimeter)

Equipment Purchase Links

• Irradiated salt:

https://www.carolina.com/specialty-chemicals-s/sodium-chloride-irradiated-crystal-laboratory-grade-20-g/888940.pr

• Hotplate:

https://www.amazon.co.uk/Uten-1250-1500W-Continuously-Thermostats-Overheating/dp/B08NHGMWFJ/ref=sr_1_6?crid=2LSNUZ83TOI6B&keywords=hot%2Bplate&qid=1641894163&sprefix=hot%2Bplate%2Caps%2C369&sr=8-6&th=1

• Aluminium foil boat:

https://www.amazon.co.uk/Trays-Muffin-Dishes-Pastry-Aluminium/dp/B08K8GDNBC/ref=sr_1_2_sspa?crid=C569LPEWSTH4&keywords=small+foil+dish&qid=1686214417&sprefix=small+foil+dish%2Caps%2C165&sr=8-2-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=1

• Safety goggles:

https://www.amazon.co.uk/Safety-Glasses-Goggles-Protective-Eyewear/dp/B08NB9H71Y/ref=sr_1_31?keywords=safety+goggles&qid=1641895343&sr=8-31

• Fire extinguisher & heat blanket:

https://www.amazon.co.uk/FireShield-Powder-Fire-Extinguisher-Blanket/dp/B08WRJ4NZT/ref=sr_1_4_sspa?crid=34SCQM4TZCJ90&keywords=fire+extinguisher&qid=1641895632&sprefix=fire+estin%2Caps%2C151&sr=8-4-spons&psc=1&spLa=ZW5jcnlwdGVkUXVhbGlmaWVyPUEzTFBMMjlaOVBPRkVUJmVuY3J5cHRlZElkPUEwNTU4NTkwMllMTFdaOTVIVlFVTCZlbmNyeXB0ZWRBZElkPUEwNzA3MjE1QVo3WExUT0owOVQ3Jnd pZGdldE5hbWU9c3BfYXRmJmFjdGlvbj1jbGlja1JlZGlyZWN0JmRvTm90TG9nQ2xpY2s9dHJ1ZQ==

• Pyrex screen:

https://www.amazon.co.uk/TANGZON-Perspex-Protection-Transaction-Partition/dp/B09V7RDNTL/ref=sr_1_1_sspa?crid=14PYUK4TXJ22L&keywords=plastic+screen&qid=1686213804&sprefix=plastic+screen%2Caps%2C146&sr=8-1-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=1

• 'Hot surface' and 'Do not touch' label:

https://www.amazon.co.uk/Caution-surface-touch-safety-sign/dp/B07YL1D9WH/ref=sr_1_5?crid=KCXGX8GB1SFM&keywords=Caution+hot+surface+do+not+touch+safety+sticker&qid=1641895790&sprefix=caution+hot+surface+do+not+touch+safety+sticker%2Caps%2C167&sr=8-5

• Eye wash kit:

https://www.amazon.co.uk/HypaClens-Eyewash-Station-Bottles-Dressings/dp/B01BLEVGWE/ref=sr_1_8?crid=1W0XIGMV0PAP8&keywords=eye%2Bwash%2Bstation&qid=1641895266&sprefix=eye%2Bwash%2B%2Caps%2C121&sr=8-8&th=1

• Tweezers:

https://www.amazon.co.uk/Tweezers-Professional-Slanted-Stainless-Precision/dp/B0971KDBHF/ref=sr_1_6?crid=18QIT7GA2OFIL&keywords=tweezers&qid=1686213918&sprefix=twee%2Caps%2C339&sr=8-6

Annex II: Bright Salt: Structural Energy Risk Assessment.

RISK ASSESSMENT

Bright Salt: Structural Energy

Activity	Structural Energy	**Demonstrator(s):**	STEM ambassador(s)
Date		**Venue:**	
Event Organiser		**Audience:**	5 – 18-year-olds and their parents / carers/ teachers
Activity Description	This activity investigates the effects of irradiation on salt crystals by heating previously irradiated salt, which causes photoluminescence and a colour change. This is linked to the real-world application of this technology in equipment to monitor radiation dose.		

Hazards	**Control Measures**
Allergies	The ambassador(s) will ask any attendees if there are any allergies that they should be aware of before the activity begins.
Chemical hazards	Chemicals have the potential to cause irritation or damage if ingested/come into contact with eyes. Eye wash station is provided. Wear Personal Protective Equipment (PPE): Eye protection (safety glasses) and chemical resistant nitrile gloves. The audience are present in only a spectator capacity and should not be hands-on during the demonstration.
Manual handling	Ambassador(s): No heavy lifting is involved in experiments to help mitigate the risk of damage to property and person. Audience: Present in only a spectator capacity, should not be hands-on during the demonstration No heavy lifting is to be carried out and experiments carried out in the appropriate environment.
Glassware hazards (irradiated salt container)	Evacuate audience from the area. Broken glassware is to be swept up disposed of appropriately, *via* glass bin or however is specified by the venue. Appropriate PPE is worn (including safety glasses and cut-proof gloves). Spilt irradiated salt should be heated until a colour change appears (the salt should go white) and disposed of in household waste.
Electrical hazards from equipment and instruments	Low voltage/current equipment is used, all equipment is stored away from water supplies. Equipment to be inspected for visual faults and to ensure PAT label is in date before demonstration commences.

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RISK ASSESSMENT

Hazards	**Control Measures**
Hot surface- burns from touching a hot surface	Turn off the hot plate when not in use. The surface of a hot plate stays hot for some time and looks the same as a "cold" plate. Avoid the unattended use of hot plates when possible. The hot plate surface should be larger than the vessel being heated. Use of a Pyrex screen with a hot surface label on to demonstrate when the hot plate is in use and to prevent audience touching the plate. The removal of the aluminium plate should be done with care using tweezers.
Slips, trips and falls	Good housekeeping to be maintained to remove potential trip and spill risks. Cables should be taped to the floor.

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

- Any PPE worn 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.

Signature: ....

Print Name: ....

Date: ....

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Annex III: Order of Radioactivity: Radiation Around Us STEM Ambassador Guide.

STEM AMBASSADOR GUIDE

Order of Radioactivity: Radiation Around Us

Objectives

Students will:

- Understand that radiation is natural and found everywhere.

Fast facts

Subject: Physics

Age range: 5+ years old

Ambassador preparation time: 30 minutes

Demonstration time required: 15 minutes

Location: Science Fair

Overview

All of us are exposed to radiation every day, from natural sources such as minerals in the ground, and man-made sources such as medical X-rays.

When people hear the word radiation, they often think of atomic energy, nuclear power, and radioactivity, but radiation has many different forms and comes from many other sources.

Radioactive objects surround us every day, in and out of our home. This activity is designed to show that radiation is everywhere and is completely safe, up to a certain limit.

Equipment

All the different items which can be used in this activity are listed at the end of the guide (Full Equipment List section). It is optional to obtain the some/ all of these items. An image pack is also included which can be used instead of or in conjunction with the below items (Radiation Around Us Image Pack).

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Procedure

Show students the everyday items or the images of the items. Ask the students to put the items in order of least radioactive to most radioactive. Included in the image pack are two radioactive signs. The dose in sieverts (Sv) will be displayed on the reverse of the images.

Answer

The table below shows the correct order for the everyday items/activities and their associated radioactivity, from lowest to highest. One sievert (Sv) is the same as one joule/kg. The sievert represents the equivalent biological effect of the deposition of one joule of radiation energy in one kilogram of human tissue.

1 Sv = 1,000 mSv = 1,000,000 µSv

Item/activity	Dose / µSv	Dose / mSv	
Smoke detector per hour at 30 cm distance	0.01	0.00001	less than
Living within 50 miles of a nuclear power plant	0.09	0.00009	
Eating 1 banana	0.1	0.0001	
Living within 50 miles of a coal power plant	0.3	0.0003	
Dental X-ray	5	0.005	
Brazil nuts, 100g	10	0.01	
Uranium glass at the surface per hour	54.2	0.0542	average
Living in a stone/ concrete/ brick building	70	0.07	
Trans-Atlantic flight	80	*0.08*	
Annual dose from natural potassium in the body	390	0.39	
Radon paint watch per hour	1920	1.92	
Head CT scan	2,000	2	
Normal UK yearly background dose	2700	2.7	
Living in Cornwall per year	6900	6.9	
Ceramic dinnerware	37500	37.5	average
Usually fatal dose	4000000	4000	

Discussion

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Talk about each item as you reveal the dose.

- **Smoke detector**

Smoke detectors use a radioactive element called Am-241 which emits charged alpha particles. The alpha radiation ionises the air particles inside the smoke detector. This allows a small electric current to flow. If there is a fire, smoke particles going into the detector are hit by alpha radiation. This reduces the ionisation of the air particles causing the current to drop. The drop in current is detected by the smoke detector, setting off the alarm.

- **Living within 50 miles of a nuclear power plant**

Most of an operating nuclear power plant's direct radiation is blocked by the plant's steel and concrete structures. An operating nuclear power plant produces very small amounts of radioactive gases and liquids, as well as small amounts of direct radiation. If you lived within 50 miles of a nuclear power plant, you would receive an average radiation dose of about 0.09 uSv per year.

- **Eating a banana**

The radioactive nature of bananas comes from the presence of Potassium, a naturally occurring mineral. The average banana contains 422 mg of potassium. About 0.012% of the atoms of potassium are radioactive, which means when they decay they emit radiation.

- **Living within 50 miles of a coal power plant**

Combustion of coal creates wastes that contain small amounts of naturally occurring radioactive material.

- **Dental X-rays**

Low levels of radiation are used in X-rays. High energy electromagnetic waves pass through the body to an x-ray detector on the other side of the patient. An image will be formed that represents the shadows formed by objects inside the body. The x-rays that are not absorbed are used to create the image. The amount the patient absorbs contributes to the patient's radiation dose. Radiation that passes through the body does not contribute to this dose.

- **Brazil nuts**

Brazil nuts are the most radioactive food that we eat. The absorb radium (a radioactive element) from the soil. In Brazil, where these nuts grow, there are elevated levels of radium in the soil.

- **Uranium glass/ vastiline glass**

Uranium glass is a glass which has had uranium added before melting for colourisation. The proportion varies from trace levels to about 2% U by weight. The added uranium was for a decorative effect, it causes the glass to be fluorescent.

- **Living in a stone/brick/concrete building for a year**

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Radioactive materials in sandstone, concrete, brick, natural stone, gypsum, and granite contain naturally occurring radioactive elements like radium, uranium, and thorium. These naturally occurring elements can break down or decay into the radioactive gas radon.

- **Trans-Atlantic flight**

When you fly you go high into the atmosphere. Up at this high altitude the air gets thinner, the higher you go the thinner the air gets and the fewer molecules there are above you to deflect cosmic rays- this is radiation from outer space.

- **Natural potassium in the body**

Potassium is an essential mineral and electrolyte in the human body. Normal levels of potassium are between 3.6 and 5.2 mmol/L of blood. Potassium is found naturally in the soil and in the food we eat

- **Watch with radon paint**

Paint containing Radon is fluorescent. In the 1920s watches painted in this uranium paint were very popular, the dials were covered in the luminous paint. They shone all the time and didn't require charging in the sun.

- **Head CT scan**

CT scans reply on x-rays to generate images. In a CT scan these X-rays are administered in all directions (360 degrees). So your body will absorb more radiation giving you a higher radiation dose.

- **Normal UK yearly background dose**

There is background radiation everywhere. The UK government estimates that the average person receives an annual dose of 2.7 mSv. About 85% of this is natural sources of background radiation, these include; radon gas excreted from rocks and soil in the ground, background cosmic radiation and living things (plants absorb radioactive materials from the soil, these pass up the food chain). Artificial sources account for about 15 per cent of the average background radiation dose. Nearly all artificial background radiation comes from medical procedures, such as receiving X-rays for X-ray photographs. A small amount of background radiation is from nuclear missile tests and nuclear power.

- **Living in Cornwall**

There is background radiation everywhere, but on average Cornwall is the most radioactive part of the British isles. This is because it is largely made up of granite, this is an igneous rock which produces radon more rapidly than most other rock types.

Radiation Around Us

- **Ceramic dinnerware**

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Often ceramics contain elevated levels of naturally occurring radionuclides. Before the 1970s, many companies used radioactive minerals to colour glazes. The most commonly used minerals were; uranium, thorium and potassium. These elements emit alpha, beta and/or gamma radiation. These glazes can be found on floor and wall tiles, pottery and other ceramics.

Real-World Application

This activity shows how radiation is present in the world around us in everyday objects and places. Therefore, radiation can be shown to be completely safe, up to a certain limit, as sources of radiation occur naturally.

Full Equipment List

- 2 Radioactive signs (big and small, representing most to least radioactive)

- Geiger counter

- Smoke detector, per hour measured at 30 cm

- Living within 50 miles of nuclear power plant (image of power plant)

- 1 banana

- Living within 50 miles of a coal power plant (image of power plant)

- Image of a dental X-ray

- Brazil nuts, 100g

- Uranium glass

- Image of a stone/concrete/brick building

- Trans-Atlantic flight ticket and/or small toy aeroplane

- Image of human body to represent annual dose from natural potassium in the body

- Radon-painted watch

- Image of a head CT scan

- Map of the UK to represent the normal UK yearly background dose

- Map of Cornwall to represent living in Cornwall for a year

- Ceramic dinnerware

- Image to represent usually fatal dose

Annex IV: Order of Radioactivity: Radiation Around Us Risk Assessment.

RISK ASSESSMENT

Order of Radioactivity: Radiation Around Us

Activity	Radiation Around Us	**Demonstrator(s):**	STEM ambassador(s)
Date		**Venue:**	
Event Organiser		**Audience:**	5 – 18-year-olds and their parents / carers/ teachers
Activity Description	This activity demonstrates that radiation is naturally present in the world around us and is safe up to a certain limit, by getting the audience to place everyday items in order of decreasing radioactivity.		

Hazards	**Control Measures**
Allergies	The ambassador(s) will ask any attendees if there are any allergies that they should be aware of before the activity begins.
General hygiene	Hand wash stations should be available or the nearest handwash point be known, as several people will handle the items.
Slips, trips and falls	Good housekeeping to be maintained to remove potential trip, slip and fall risks.
Sharp objects - scissors	Scissors are provided should the STEM ambassador(s) wish to print some images and cut them out. Handle these with care and keep stored away from students and their parents/ carers.

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

- Appropriate ventilation and hygiene facilities should be present.

Signature: ....

Print Name: ....

Date: ....

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NATIONAL NUCLEAR LABORATORY

Annex V: For Your Glove: Nuclear Contamination Demonstration STEM Ambassador Guide.

STEM AMBASSADOR GUIDE

For Your Glove: Nuclear Contamination Demonstration

Objectives

Students will:

- Explain the difference between contamination and irradiation.
- Understand the precautions related to the spread of contamination.

Fast facts

Subject: Chemistry

Age range: 5+ years old

Ambassador preparation time: 30 minutes

Demonstration time required: 5 minutes

Location: Science Fair

Overview

Radiochemists have to work carefully to prevent the spread of radioactive material. They must take special precautions to ensure that the radioactive material doesn't get ingested or onto their skin. To do this, radiochemists have a special way of removing their gloves. There is a technique that they use to take off their gloves which stops any of the radioactive material from touching the scientist's skin.

This activity gets the students to have a go at using the glove removal technique, where they can visually see if they've been able to prevent the spread of contamination by using UV powder and a black light (a UV torch).

Equipment

- UV powder and black light (set)
- Nitrile Gloves
- Bin/bucket
- Kitchen paper

Links to purchase the equipment are given at the end of the guide (Equipment Purchase Links section).

STEM AMBASSADOR GUIDE

Nuclear Contamination Demonstration

Procedure

Ask the students to put on a pair of gloves and dab the UV powder around their hands. Ask the students to take these gloves off as cleanly as possible and place the gloves in the bin. Following this, shine a UV light on the student's hand to examine whether they've been able to contain the material.

Answer[1]

1. When removing outer gloves, the exposed side of the outer layer is considered "dirty" and the inner glove is considered "clean." Contact of a clean surface should be made only by another clean surface.
2. Grasp the outside of one glove, near the wrist, using the other gloved hand.
3. Peel the glove away from the hand, turning it inside out as it is removed.
4. While holding the removed glove with the remaining "dirty" gloved hand, insert the "clean" tip of one finger underneath the edge of the remaining "dirty" glove at the wrist opening.
5. Peel the second outer glove off, turning it inside out as it is removed.
6. Keep holding the first glove until the second glove envelopes the first and both are contained in a single package, with both gloves inside out, one inside the other.
7. Place the gloves into the appropriate waste receptacle.

Discussion

Contamination is the presence of unwanted radioactive material.

Radiation is energy that moves from one place to another in a form that can be described as waves or particles. Radiation is emitted from the contamination due to the decay of the radioactive nuclei present in the contamination.

The two processes of irradiation and contamination are often confused. However, they are very different and can be used in their own right[2].

[1] https://www.epa.gov/sites/default/files/2015-05/documents/402-r-12-005_contamination_guide_aug_2012.pdf
[2] https://www.bbc.co.uk/bitesize/guides/z83dxfr/revision/2

STEM AMBASSADOR GUIDE

Nuclear Contamination Demonstration

Irradiation	Contamination
Occurs when an object is exposed to a source of radiation outside the object	Occurs if the radioactive source is on or in the object
Doesn't cause the object to become radioactive	A contaminated object will be radioactive for as long as the source is on or in it
Can be blocked with suitable shielding	Once an object is contaminated, the radiation cannot be blocked from it
Stops as soon as the source is removed	It can be very difficult to remove all of the contamination

Real-World Application

Radiochemists have to work carefully to prevent the spread of radioactive material, to ensure that radioactive material doesn't get ingested or onto their skin. To do this, radiochemists wear gloves when handling radioactive material, and use the technique that the students attempt in this activity to remove them safely once they have finished their work. Once the gloves have been safely removed, they are then securely disposed of as radioactive waste.

Equipment Purchase Links

- UV powder and black light (set):

https://www.amazon.co.uk/Colour-Glow-Dark-Pigment-Powder/dp/B07VBJFGKC/ref=sr_1_5?keywords=uv+powder&qid=1669042194&sr=8-5

- Nitrile gloves:

https://www.amazon.co.uk/Nitrile-Powder-Multi-Purpose-Gloves-Disposable/dp/B08FZPVFRG/ref=sr_1_1_sspa?crid=EY90E31SIWYH&keywords=plastic+gloves&qid=1669042321&sprefix=plastic+gloves%2Caps%2C94&sr=8-1-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=1&smid=AOZNBK3FJUV5Y

- Bin/bucket:

https://www.amazon.co.uk/Household-Easy-Grip-Multipurpose-Cleaning-Gardening/dp/B08BWK6F3L/ref=sr_1_2_sspa?crid=NRZH2BDABYS3&keywords=bucket&qid=1669042269&sprefix=bucket%2Caps%2C135&sr=8-2-spons&sp_csd=d2lkZ2V0TmFtZT1zcF9hdGY&psc=1

Annex VI: For Your Glove: Nuclear Contamination Demonstration Risk Assessment.

AUGMENTED CINCH

RISK ASSESSMENT

For Your Glove: Nuclear Contamination Demonstration

Activity	Nuclear Contamination	**Demonstrator(s):**	STEM ambassador(s)
Date		**Venue:**	
Event Organiser		**Audience:**	5 – 18-year-olds and their parents / carers/ teachers
Activity Description	This activity gets the audience to have a go at using the glove removal technique which is used by all nuclear workers to safely remove their contaminated gloves.		

Hazards	**Control Measures**
Allergies	The ambassador(s) will ask any attendees if there are any allergies that they should be aware of before the activity begins, **particularly to the nitrile gloves.**
Spillage of UV powder	Kitchen roll is available to clean up any minor spills. At most the likely spill amount will be about 1 g of UV powder. This can be cleaned up with kitchen roll and binned. For residues on the person's hand, hand sanitiser will be on hand and the nearest hand wash point known. Judgement by ambassador(s) will be made whether audience can handle the stock UV powder and suggestion made to dispense this on behalf of the audience. Experiments are carried out at the table and not taken away.
UV powder ingestion	UV powder is to be handled by ambassador(s) and no more than roughly 1 g is to be given out per experiment. UV powder boxes are always under supervision of the ambassador(s).
UV powder – staining of clothing	UV powder is to be kept under supervision of the ambassador(s). Containers are to be kept closed when not in use. Kitchen roll is available to clean up spills. UV powder is non-toxic but may stain skin and clothes.
Waste	Used nitrile gloves are bulked into a bucket under the table. When this bucket is full an ambassador can dispose of this *via* household waste or whatever route is specified by the venue.
Injury – heavy weight	The black light can be heavy. There is a risk it could be dropped onto a foot. The experiment is run under supervision and the black light is to be handled with care. It is at the ambassador's discretion if the participant can handle the light. Ambassador(s) are to emphasise this light is not to be shone in anybody's eye.

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NATIONAL NUCLEAR LABORATORY

AUGMENTED CINCH

RISK ASSESSMENT

Hazards	**Control Measures**
Slips, trips and falls	Good housekeeping to be maintained to remove potential trip, slip and fall risks. This activity requires movement. Ensure there is large enough area to perform the activity and there are no hazards nearby. The ambassador(s) should emphasise the importance of being aware of your surroundings.

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

- Appropriate ventilation and hygiene facilities should be present.

Signature: ....

Print Name: ....

Date: ....

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NATIONAL NUCLEAR LABORATORY

Annex VII: Nuclear Energy: I'm in the middle of a (nuclear) chain reaction STEM Ambassador Guide.

Nuclear Energy: I'm in the middle of a (nuclear) Chain Reaction

Objectives

Students will:

- Make predictions.
- Understand nuclear fission using a model.
- Demonstrate the concept of a chain reaction.

Fast facts

Subject: Chemistry/Physics

Age range: 5+ years old

Ambassador preparation time: 15 minutes

Demonstration time required: 15 minutes

Location: Science Fair

Overview

Nuclear fission is the process of an unstable atom (uranium-235 or plutonium-239) splitting into two smaller atoms (fission products), producing two or three free neutrons and releasing a very large amount of energy. Fission is the process by which energy is produced in a nuclear reactor. To control this reaction, control rods are used.

The students will take part in a practical demonstration to help understand how a large atomic nucleus can be split into two smaller particles, which will release neutrons and create a chain reaction.

Equipment

- Balloons

Links to purchase the equipment are given at the end of the guide (Equipment Purchase Links section).

Precautions

Ensure there are no trip hazards present, and you have a large enough floor area for a small group to gather. Ensure no one is allergic to the latex in the balloons, if so, ensure that they wear gloves.

Procedure

1. Have the students stand in a tightly packed group and give each student two balloons.

2. In a fission reaction, a neutron must be released to get the reaction going. The students are going to simulate nuclear fission reactions by throwing 'neutrons' (balloons).

3. Start the simulation by asking one student to throw their 'neutron' (balloon) into the air.

4. If the 'neutron' (balloon) touches a student, the student should throw both of their balloons in the air. This will continue until all the balloons are in the air.

5. Retrieve all the balloons and reset so that each student has two again. However, this time select a couple of students to be 'control rods'. Their job is to grab balloons out the air during the 'reaction'. Control rods are used to prevent fission reactions spiralling out of control and becoming dangerous. The amount of fission rods that are present will affect the rate of the nuclear reaction. Begin the 'reaction' again and let it run for a few minutes.

What is different about this reaction?

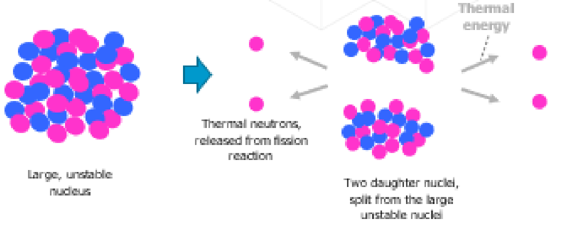
6. Repeat a few times adding or taking away 'control rods'.

7. You can now discuss nuclear fission, how we control nuclear reactors, what is a chain reaction and critical/sub/supercritical masses with the students.

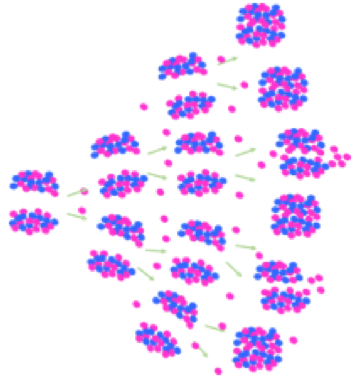
Discussion

There are two kinds of nuclear power; fission and fusion. Both types of reaction release energy and during each the centre of the atom (nucleus) is changed. Nuclear fission works by splitting the nucleus apart. Uranium-235 or plutonium-239 are two isotopes that are often used in fission reactions. They have massive, unstable nuclei that can be used to start a chain reaction.

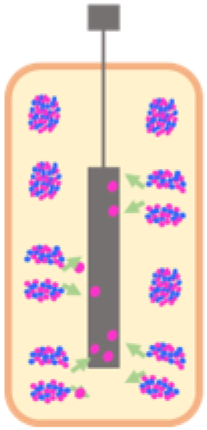
In nuclear fission the bonds that hold a nucleus together are broken and thermal energy is released. The remaining parts of the original nucleus then form two daughter nuclei with roughly equal mass, as well as some thermal neutrons.



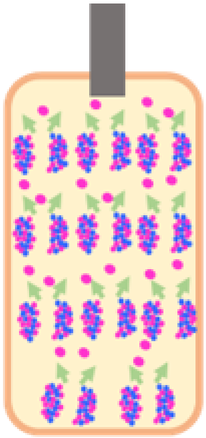
These thermal neutrons can be used to start a chain reaction. When these neutrons collide with other unstable nuclei they can cause a chain reaction. Each fission reaction produces more neutrons which can collide with more nuclei, extending the process indefinitely and producing more and more energy.



If uncontrolled this chain reaction can release so much energy that it could cause an explosion. Nuclear reactors control this reaction using control rods. They contain elements of boron, silver, indium, or cadmium to absorb some of the neutrons. Lowering and raising the rods into the reactor can control the rate of the reactions, allowing the energy from the reactions to be harnessed to generate electricity. In a nuclear power station, this is done by using the heat energy from the fission reactions to boil water and make high pressure steam. This steam turns a turbine, which turns a generator and generates electricity.



Nuclear reactor with control rod lowered. The control rod is absorbing neutrons to keep the reaction proceeding at a safe and steady rate.



Nuclear reactor with control rod lifted. With no control rod there are many thermal neutrons and a chain reaction is occurring with lots of thermal energy

Equipment Purchase Links

- Balloons:

https://www.amazon.co.uk/Balloons-12-inch-Multicoloured-Decorations/dp/B0BGLCKRCH/ref=sr_1_9?crid=EUT2SXNE4J1Z&keywords=balloons%2Bmultipack&qid=1692006357&sprefix=baloons%2Bmutipack%2Caps%2C106&sr=8-9&th=1

Annex VIII: Radioactive Nuclei: Decay and Half-Life Demonstration STEM Ambassador Guide.

STEM AMBASSADOR GUIDE

Radioactive Nuclei: Decay and Half-Life Demonstration

Objectives

Students will:

- Understand the concepts of radioactive decay and half-life using a model.
- Demonstrate that radioactive decay is a random process.
- An optional extension activity is available where the students can explore the concept of different nuclides having different half-lives.

Fast facts

Subject: Physics

Age range: 12+ years old

Ambassador preparation time: 30 minutes

Demonstration time required: 15 minutes

Location: Science Fair

Overview

Radioactive decay is the process by which an unstable nucleus releases energy in the form of particles or waves, to become more stable. This process happens over time and nuclei have a certain probability of decaying, but it is random as to which individual nucleus will decay. **The time taken for half of the radioactive nuclei in a sample to have decayed is known as the half-life.**

The students will take part in a practical activity to demonstrate the random decay of radioactive nuclides, modelled as skittles, and calculate the half-life in terms of box shakes.

Equipment

- Skittles
- Paper cups
- Cardboard boxes
- Pens
- Charts to measure half-life (Chart Template document)

Links to purchase the equipment are given at the end of the guide (Equipment Purchase Links section).

STEM AMBASSADOR GUIDE

Decay and Half-Life Demonstration

Procedure

1. Prior to the science fair, assemble the cardboard boxes and draw a circle roughly in the centre of the base of each box. This is best done using a marker pen, but a biro can be used if a marker pen is not available. Either the template circle (Circle Template document) can be cut out or the rim of a reasonably sized mug can be used as a template to aid circle drawing, if beneficial.

2. Begin by briefly discussing some of the information in the discussion section below with the students, so they understand the basics about unstable nuclei and radioactive decay and how this links to the model they are about to use.

3. Give each student a cup of skittles, each of which has a similar number of skittles in it (approximately 40–80, there are about 135 skittles per 150 g bag), a box, a chart, and a pen.

4. Ask the students to count the number of skittles in their cups and record the number in the first box in the chart. Then they must empty their cups into the boxes they have been given.

5. Next, get the students to shake their boxes and take out the skittles which are inside the circle. Ask them to count the number they have taken out, record the number in the chart, and then replace them in the cup. Finally, get the students to subtract the number of skittles they have just removed from the number remaining in the box from the previous shake and record this in the chart.

6. Repeat step 4 several times, until the students have at least less than half the skittles left in the box.

7. You can now discuss radioactive decay and half-life further with the students and get them to calculate the half-lives of their 'nuclides' in terms of the number of shakes of the box.

8. At the end of the activity the students can take their skittles with them, if they so wish. Collect all the boxes back in and re-use as many cups as possible to save resources the next time this activity is run.

Discussion

Atoms all have a nucleus at their centre, made up of protons and neutrons. Isotopes of an element are atoms which have the same number of protons in their nuclei but a different number of neutrons. In some isotopes, the forces in the nucleus are unbalanced because there are too many protons or neutrons. Nuclei with balanced forces are stable and have much less energy, whereas those with unbalanced forces are unstable and have lots of energy.

STEM AMBASSADOR GUIDE

Decay and Half-Life Demonstration

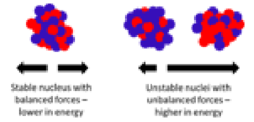


Figure 1 Stable and unstable nuclei

Unstable nuclei can release some of their excess energy by emitting particles or waves. This process is called radioactive decay and the particles or waves released are types of radiation. There are three types of radioactive decay processes. These are known as alpha decay, beta decay and gamma decay. In alpha and beta decay, a particle is emitted from the unstable nucleus, but in gamma decay a wave is emitted. Unstable nuclei undergo radioactive decay until they release enough energy to become stable.

Radioactive decay happens over time. For a given sample of unstable nuclei, over a certain period of time all of the nuclei will eventually decay, but they do not all decay at once. Ask the students to think about their starting number of skittles and imagine that these are the unstable nuclei before they have decayed. Explain that the skittles from the box which land in the circle and they take away after shaking are the nuclei that decay. This shows that it is completely random which individual nucleus will decay at any given time, as it is completely random which skittle lands in the circle after the box is shaken. However, it also shows that the nuclei decay over time, as there are fewer skittles left in the box each time it is shaken.

The time taken for half the number of nuclei in the sample to decay is known as the half-life. Get the students to calculate half of the number of skittles that they started with in the box. Then ask them to count how many times they shook the box before the number of skittles that was left in the box was less than half the starting number. This is the half-life of their sample in terms of box shakes. If the students compare between themselves, their half-lives should all be fairly similar.

$$\text{half life} = \frac{\text{half no. of skittles you started with}}{\text{no. of box shakes}}$$

Equation 1: half life in terms of box shakes

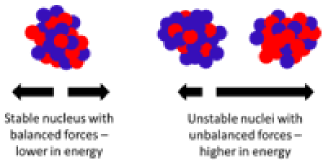


Figure 1 Stable and unstable nuclei

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Equation 1: half life in terms of box shakes

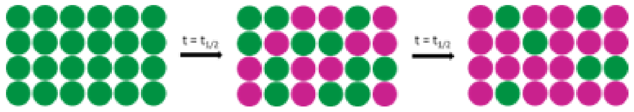


Figure 2 Sample of green nuclei decaying randomly to form pink nuclei with a half-life of $t_{1/2}$

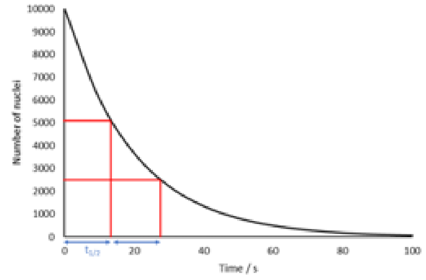


Figure 3 Decay curve for a sample of nuclei with half-life of $t_{1/2}$

Real-World Application

The understanding of radioactive decay and the half-lives of different nuclei is very important to radiation workers. This is because knowing how much energy unstable nuclei emit and how quickly ensures that radiation workers can properly protect themselves against the damage that the waves or particles released in radioactive decay can cause to the body. As well as this, the types of decay and the half-lives of nuclei are used to work out which isotopes will be present in spent nuclear fuel after it has been used and in the future. This means that nuclear waste can be handled, stored and disposed of safely, so we can protect both people and the environment.

Optional Extension

The half-lives of nuclei are different for different isotopes. Some isotopes can have very long half-lives, like uranium-238 which has a half-life of 4.468 billion years, whereas others can have very, very short ones, like astatine-215 which has a half-life of 0.1 milliseconds.

Get the students to repeat the above procedure, but this time using boxes which are lined with a bigger/smaller circle template, or get them all to draw differently sized circles in the boxes. Using a different coloured pen will make this easier.

Annex IIX: Radioactive Nuclei: Decay and Half-Life Demonstration Risk Assessment

RISK ASSESSMENT

Radioactive Nuclei: Decay and Half-Life Demonstration

Activity	Imposter Demonstration	**Demonstrator(s):**	STEM ambassador(s)
Date		**Venue:**	
Event Organiser		**Audience:**	11 – 18-year-olds and their parents / carers/ teachers
Activity Description	This activity models the decay of radioactive nuclei and investigates the concept of half-life using sweets and cardboard boxes.		

Hazards	**Control Measures**
Allergies	The ambassador(s) will ask any attendees if there are any allergies that they should be aware of before the activity begins.
General hygiene	Hand wash stations should be available or the nearest handwash point be known. The ambassador(s) will wear gloves when distributing the sweets (skittles).
Slips, trips and falls	This activity requires movement. Ensure there is large enough area to perform the activity and there are no hazards nearby. Pick up any dropped items immediately. The ambassador(s) should emphasise the importance of being aware of your surroundings.

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

- Appropriate ventilation and hygiene facilities should be present.

Signature: ....

Print Name: ....

Date: ....

NATIONAL NUCLEAR LABORATORY

Annex IX: Imposter: Keeping Nuclear Materials Safe STEM Ambassador Guide.

STEM AMBASSADOR GUIDE

Imposter: Keeping Nuclear Materials Safe

Objectives

Students will:

- Understand that nuclear materials have the potential to be used for non-peaceful purposes, but there are lots of robust systems in place to prevent this from happening.
- Understand that there are measures in place to keep people, the environment and nuclear materials safe.

Fast facts

Subject: Chemistry/Physics

Age range: 11+ years old

Ambassador preparation time: 10 minutes

Demonstration time required: 20 minutes

Location: Science Fair

Overview

The activity is designed to raise awareness and understanding that adoption of advanced nuclear technologies presents challenges that must be addressed.

A critical component of benefiting from nuclear technologies is our ability to ensure that the sector's sites, materials, technology and people remain safe and secure. Jobs involved in these safeguarding activities make up a large and important part of the nuclear sector.

Equipment

- Blu-tac
- Periodic table card packs
- Pin boards
- Pens
- Paper
- Scissors

STEM AMBASSADOR GUIDE

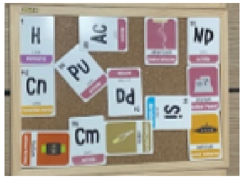
Keeping Nuclear Materials Safe

Procedure

This activity is designed for small groups of between 4 and 10 but could work for slightly larger groups if needed. There are 3 sets of equipment provided in the box, so the kit can accommodate from 1 to 3 small groups. More kits can be purchased to accommodate for more groups.

The activity works best with two or more groups so it can turn into a competition, but can be run with only one group.

In the kit there will be one pin board with radioactive elements cards arranged in a 'random' pattern and blue tacked down. It should look like the below:



If you are making your own kit, then arrange and blu-tac in place one set of cards to look similar to the above.

There needs to be at least one imposter per team and for larger teams you may want two. This is at the discretion of the STEM ambassador. Cut the paper into small pieces and onto one piece of paper write 'imposter'. Deal the paper out to the participants so that one (or 2) participant(s) in each team receive a slip saying 'imposter'.

Make it clear that they should not tell the other group members that they are the imposter.

Collect the slips back in. The students will then be given the task to recreate the board above. They will be given a pin board and a full pack of periodic table cards.

The STEM ambassador will stand away from the groups (e.g. outside, round a corner etc...) with the completed pin board. The students will be allowed to come up to the board one at a time, for 10 seconds max, then they will return to their group. The next team member will then be allowed to come up to the completed board for 10 seconds max etc..., working round the entire group for 7 minutes. As a team they will do their best to piece together and recreate the puzzle. **But** there is an imposter. The imposter will attempt to sabotage their team recreating the puzzle. They might hide some of the group's cards, put cards in the wrong place, suggest the wrong card altogether, accuse someone else of being the imposter, or act in other ways to try prevent their group recreating the puzzle correctly.

STEM AMBASSADOR GUIDE

Keeping Nuclear Materials Safe

Before the challenge begins the students are allowed 1 minute to come up with a strategy as to how they will tackle their challenge. They could work to sperate the cards out into colours to help find them quicker, memorise the board in a clockwise fashion, work in pairs to check each other's work as some possible suggestions for strategy ideas.

Once time is up each group will present their completed board and it will be compared to the demonstration board. Below, the demonstration board is in the middle, team one's board is on the left and team two's board is on the right. Group two won this challenge.

Team one's board | Demonstration board | Team two's board

Once the winner has been revealed ask the group members, one group at a time, who they think their imposter was and why. Then ask the imposter to reveal themselves. Ask the group how it made them feel knowing they were working with an imposter. What measures could be put in place to stop imposters? Why is this especially important in the nuclear sector?

You can now explain to the students that the activity is designed to raise awareness and understanding that working with nuclear materials presents challenges that must be addressed.

Discussion and Real-World Application

Nuclear science is nothing new. Nuclear science is used across the world every day, whether it is contributing to the achievement of net zero through the generation of carbon neutral energy, advancing nuclear science for the delivery of effective healthcare, in food and agriculture, or even in space exploration. However, there is a possibility that nuclear technology can be diverted to non-peaceful purposes. A critical component of a society benefiting from nuclear technology is to ensure that nuclear sites, technologies and materials remain safe and secure.

STEM AMBASSADOR GUIDE

Keeping Nuclear Materials Safe

Nuclear security is the prevention, detection of and response to theft, sabotage, unauthorised access, illegal transfer or other malicious acts involving nuclear material and other radioactive substances or their associated facilities. This is done to protect people, property, society and the environment from the harmful effects of ionizing radiation. Scientists need to work alongside government to create policy, inspections of nuclear material and actions to stop nuclear material being used for non-peaceful purposes.

In the activity the students have just completed, the imposter represents only one of the many potential threats to the nuclear industry. This highlights how important it is for workers in the nuclear industry to be aware of the different threats posed and be vigilant.

Equipment Purchase Links

• Blu-tac

https://www.amazon.co.uk/Bostik-Multipurpose-Reusable-Adhesive-Non-Toxic/dp/B0001OZI70/ref=sr_1_5?crid=1GMD3AMFKVJ1H&keywords=blu+tack&qid=1692346767&sprefix=bu+tac%2Caps%2C353&sr=8-5

• Periodic table card packs

https://www.amazon.co.uk/gp/product/B075DFF22T/ref=ppx_yo_dt_b_asin_image_o06_s01?ie=UTF8&psc=1

• Pin boards

https://www.amazon.co.uk/gp/product/B08LQJ6ZN6/ref=ppx_yo_dt_b_asin_image_o04_s00?ie=UTF8&psc=1

• Pens

• Paper

• Scissors

Annex X: Imposter: Keeping Nuclear Materials Safe Risk Assessment

RISK ASSESSMENT

Imposter: Keeping Nuclear Materials Safe

Activity	Imposter Demonstration	**Demonstrator(s):**	STEM ambassador(s)
Date		**Venue:**	
Event Organiser		**Audience:**	11 – 18-year-olds and their parents / carers/ teachers
Activity Description	Groups of students will play a memory game using periodic table flash cards. The game will have an imposter who is trying to sabotage the group's efforts.		

Hazards	**Control Measures**
Allergies	The ambassador(s) will ask any attendees if there are any allergies that they should be aware of before the activity begins.
General hygiene	Hand wash stations should be available or the nearest handwash point be known. The ambassador(s) will wear gloves when distributing the sweets (skittles).
Slips, trips and falls	This activity requires movement. Ensure there is large enough area to perform the activity and there are no hazards nearby. Pick up any dropped items immediately. The ambassador(s) should emphasise the importance of being aware of your surroundings.

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

- Appropriate ventilation and hygiene facilities should be present.

Signature: ....

Print Name: ....

Date: ....

NATIONAL NUCLEAR LABORATORY

Annex XI: Nuclear Medicine: Separating Radionuclides STEM Ambassador Guide.

Nuclear Medicine: Separating Radionuclides

Objectives

Students will:

- Understand how nuclear materials are used for medical purposes.
- Understand why half-lives are important in nuclear medicine and how we separate different isotopes.

Fast facts

Subject: Chemistry

Age range: 16+ years old

Ambassador preparation time: 30 minutes

Demonstration time required: 20 minutes

Location: Science Fair

Overview

In 21st century medicine, radioisotopes play a huge role in cancer treatments and diagnostics.

As medicine develops the use of radioisotopes will increase.

This activity highlights how radionuclides with specific properties are separated and isolated for their use in cancer treatments. Specifically, a new type of treatment called Targeted Alpha Therapy (TAT) is considered.

Equipment

All the different items which can be used in this activity are listed at the end of the guide (Full Equipment List section).

Background

This demonstration has been designed for use at science fairs. It is designed to represent the rigs used by the Health and Nuclear Medicine (H&NM) team to extract yttrium from nuclear waste, which could then be used in medicinal applications. This activity is designed to be demonstrated after a brief introduction to nuclear medicine.

The concept of the demonstration is that the columns filled with cotton wool balls represent the real columns and ion exchange resin used by H&NM research teams. The white cotton wool balls at the start represent a clean ion exchange resin. As the black water, representing nuclear waste that contains many elements but this case specifically strontium, is poured in, the white cotton wool balls are stained black. This is to show the binding of the strontium to the ion exchange resin.

The second column filled with black cotton wool balls and skittles represents the column after time. The black cotton wool balls show that the strontium in the original nuclear waste (which turned the white cotton wool balls black) is still there, but some has decayed into new elements (the skittles). The new elements have weaker bonding to the ion exchange resin and can be washed off the column using acid. When adding the water to the second column, the colour should be washed off the skittles, highlighting that these daughter products can be removed, whilst the strontium remains.

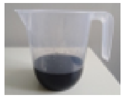
The red coloured water can then be shown to be extracted and taken to be made into medicine.

Procedure

Before the science fair begins:

1. Ensure you are located close to a tap, if not collect some water using a jug or appropriate container.

2. Fill a jug with roughly 100 mL of tap water and add enough black food colouring to the water to get a dark black colour to the water. This represents the nuclear waste. Use this dyed water to dye some cotton wool balls black.



3. Fill one jug with water. This represents acid.

4. Set up two retort stands on an appropriate level surface, probably a table.

5. Clamp a chromatography column to each retort stand. Ensure the taps at the bottom are shut.

6. Fill one column with white cotton wool balls. This represents a pristine column of ion exchange resin.

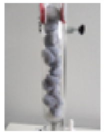
7. Fill one column with a mixture of black cotton wool balls and skittles. This represents a column after a month of decay. Place a glass beaker beneath this column to collect the red dyed water (daughter isotopes).

Starting the demonstration:

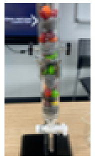
1. Go through the background information with the students; the supporting slide pack can be used to help explain and visualise the demonstration. Highlight the white cotton wool balls showing that there is only hydrogen bound to the ion exchange resin. Pour the 'nuclear waste' black water into the column from the jug. Make sure the tap is shut before pouring in the water. Pour the black water into a level at which all the cotton wool balls are only just submerged ensuring the cotton wool balls do not float too much out of the water.

2. Whilst the cotton wool balls are absorbing the colour explain the columns filled with cotton wool balls represent the real columns and ion exchange resin used by H&NM research teams. The white cotton wool balls at the start represent a clean ion exchange resin. As the black water, representing nuclear waste that contains many elements but this case specifically strontium, is poured in, the white cotton wool balls are stained black. This is to show the binding of the strontium to the ion exchange resin.

3. After 3 / 4 minutes the cotton wool balls will have absorbed the colour. Open the tap and release the black water into a beaker. Show that the cotton wool balls are now stained black/grey, indicating strontium and other elements are now bound to the resin.



4. Show the second column containing the black cotton wool balls and skittles. Point out that the skittles represent daughter elements such as yttrium growing into the column, whilst undecayed strontium is still present.



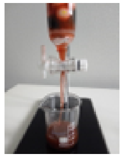
5. Pour the jug of 'acid' (water) into the column containing the skittles, until all the cotton wool balls and skittles are submerged. Make sure the tap is closed before pouring in the water. Whilst waiting for the colour to wash off, explain that the second column filled with black cotton wool balls and skittles is supposed to represent the column after time. The black cotton wool balls show that the strontium in the original nuclear waste (which turned the white cotton wool balls black) is still there,

STEM AMBASSADOR GUIDE
Separating Radionuclides

but some has decayed into new elements (the skittles). The new elements have weaker bonding to the ion exchange resin and can be washed off the column using acid. When adding the water to the second column, the colour should be washed off the skittles, highlighting that these daughter products can be removed, whilst the strontium remains.

6. After a few minutes the colour of the skittles should now be washed off, turning the water reddish. Explain that the yttrium was washed off the ion exchange column as it is less strongly bound.

7. Open the tap of the column and catch the red water into a beaker.



8. Show that the beaker full of red liquid now contains the isotopes we need to make the alpha therapy medicine explained in the slides. The black cotton wool balls show that there is still undecayed strontium in the column. Explain that this will also decay, and we can repeat the process of extracting yttrium multiple times. Finish the presentation by summarising that this is how we make medicine from nuclear waste

Clean up

A bucket is provided; empty all the waste contents into the bucket. The liquids can be disposed of down a sink and the solids into a bin or however else specified by the venue. The cotton wool balls can get stuck in the glass columns; tweezers are provided to help remove them. Dismantle and clean all the kit before returning it to the box. The glass columns are fragile so must be returned to the carboard boxes before being placed into the larger box.

Discussion and Real-World Application

Atoms are made up of a positively charged nucleus at their centre surrounded by negatively charged electrons. The nucleus contains both positively charged protons and neutrons, which have no charge. The stability of a nucleus depends on the balance between the number of neutrons and protons. Elements higher up in the periodic table, which have fewer protons, are stable if they have the same number of protons and neutrons in their nucleus. For example, carbon-12 is stable as it has 6 protons and 6 neutrons. However, for elements lower down in the periodic table, with an increasing number of protons, more neutrons are needed to keep the nucleus stable. For example, stable lead-206 has 82 protons and 124 neutrons.

STEM AMBASSADOR GUIDE
Separating Radionuclides

Nuclei that have too many or too few neutrons are unstable and have a higher amount of energy. They can release some of the excess energy by emitting particles or waves. This process is called radioactive decay and the particles or waves released are types of radiation. Three types of radioactive decay processes are alpha decay, beta decay and gamma decay. In alpha and beta decay, a particle is emitted from the unstable nucleus, but in gamma decay a wave is emitted.

Isotopes of an element are atoms which have the same number of protons in their nuclei but a different number of neutrons. Radioisotopes are isotopes which have unstable nuclei which are therefore radioactive. In modern medicine, radioisotopes play an essential role in wide range or treatments and diagnostics. Diagnostic medical radioisotopes account for 95 % of all nuclear medicinal procedures undertaken each year.

Targeted Alpha Therapy (TAT) is a new area of cancer treatment and research in nuclear medicine. TAT involves the delivery of a radionuclide species to cancer cells using artificially made biological molecules. These biological molecules can selectively attach to the surface receptors of a cancer cell without affecting healthy tissue. Once attached to the cancer cells, the radionuclide decays, releasing an alpha particle. These alpha particles damage the cancer cells, leading to cell death. In most current cancer treatments both heathy and cancerous cells are attacked. However, in TAT, the use of the highly selective biological molecules combined with short range, highly toxic alpha particles can ensure that the dose delivered to the cancerous cells is maximised, while damage to the surrounding healthy tissue is limited.

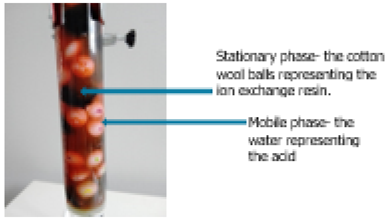
Very specific radionuclides with appropriate half-lives are required for TAT. The half-life of an isotope is the time it takes for half the radioactive nuclei in a sample to decay to half of its original activity. For example, strontium-90 (Sr) has a half-life of 29 years. Therefore, the activity of any given sample of strontium would fall to 50% of its original value after 29 years. After another 29 years (58 years in total) the strontium activity would be 25% of its original value, etc...

A radionuclide must have a relatively short half-life to be suitable for use in the body in cancer treatments and diagnostics. This is such that the radionuclide can exist in the body long enough to irradiate (treat) the cancerous tumour, but it is not around long enough to cause damage to healthy tissue. Strontium's half-life of 29 years is too long because after 58 years only 75 % of the strontium will have decayed away and there would still be 25 % of the initial strontium left. However, yttrium has a half-life of 3 days, and therefore it only takes 6 days for 75 % of the yttrium to decay away.

It is essential that scientists ensure that samples of radioisotopes used for TAT are pure, because the radioisotope is being put in the human body, and any other radioactive impurities could lead to long-lasting damage to healthy cells. A technique used for the separation and purification of radionuclides is extraction chromatography. Extraction chromatography is performed using a column. There are three main components: the inert support; the stationary phase and the mobile phase.

As described above, yttrium-90 has a half-life which makes it suitable to be used in TAT, but that of strontium-90 is far too long. As strontium-90 decays into yttrium-90, we must make sure that the yttrium-90 is separated successfully from the strontium-90 and there is no strontium-90 remaining.

To separate them, we load the strontium-90 into the inert support, and then when it decays into yttrium-90 we can use a mobile phase (usually an acid) to wash ONLY the yttrium-90 off.



Equipment List

• Glass chromatography columns

https://www.amazon.co.uk/gp/product/B082Y3SZLP/ref=ppx_yo_dt_b_asin_image_o03_s01?ie=UTF8&th=1

• Clamps and stands

https://www.amazon.co.uk/gp/product/B08B1MSBR4/ref=ppx_yo_dt_b_asin_image_o03_s00?ie=UTF8&th=1

• Cotton wool balls

https://www.amazon.co.uk/gp/product/B086ZW6G2M/ref=ppx_yo_dt_b_asin_image_o01_s00?ie=UTF8&psc=1

• Dark food colouring

https://www.amazon.co.uk/PME-100-Natural-Food-Colouring/dp/B00AZZ231E/ref=d_bmx_dp_i81folpo_sccl_2_2/258-9540456-5138321?pd_rd_w=Dsual&content-id=amzn1.sym.ce222b41-ab01-46b1-98f5-4cec49a59a08&pf_rd_p=ce222b41-ab01-46b1-98f5-4cec49a59a08&pf_rd_r=1DB1BZ02KXZCF2NXM7XM&pd_rd_wg=h9w2f&pd_rd_r=ec1a9ea2-a8a0-4b76-9945-b5b0305954dc&pd_rd_i=B00AZZ231E&psc=1

• Skittles

https://www.amazon.co.uk/gp/product/B08G9Z14PT/ref=ppx_yo_dt_b_asin_image_o01_s00?ie=UTF8&th=1

• Glass beakers

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https://www.amazon.co.uk/gp/product/B09Z5XSLGD/ref=ppx_yo_dt_b_asin_image_o00_s02?ie=UTF8&psc=1

• Plastic jugs

• Tweezers

https://www.amazon.co.uk/gp/product/B07QNZFXFN/ref=ppx_yo_dt_b_asin_image_o09_s00?ie=UTF8&th=1

• Dustpan and brush

https://www.amazon.co.uk/Faithfull-BRDUSTSET-Dustpan-Brush-Set/dp/B00601XFIM/ref=sxts_b2b_sx_reorder_acb_customer?content-id=amzn1.sym.e5b2eef0-5ac6-4452-a455-3ac580647cad%3Aamzn1.sym.e5b2eef0-5ac6-4452-a455-3ac580647cad&crid=SKE6C0QX4JL1&cv_ct_cx=dustpan+and+brush&keywords=dustpan+and+brush&pd_rd_i=B00601XFIM&pd_rd_r=b129a089-3a6c-408d-b3d0-5f65a24ed706&pd_rd_w=5imn8&pd_rd_wg=qoN9E&pf_rd_p=e5b2eef0-5ac6-4452-a455-3ac580647cad&pf_rd_r=N3YDPAA9B7ZRWP9YY3PB&qid=1692368187&s=diy&sbo=RZvfv%2F%2FHxDF%2BO6021pAnSA%3D%3D&sprefix=%2Cdiy%2C326&sr=1-1-c8a51df4-6015-4603-b82a-8c2c24cf7e97

• Cut-proof gloves

https://www.amazon.co.uk/gp/product/B07KSXDL33/ref=ppx_yo_dt_b_asin_image_o00_s01?ie=UTF8&th=1

• Bucket

https://www.amazon.co.uk/gp/product/B00FPMZ8VE/ref=ppx_yo_dt_b_asin_image_o07_s01?ie=UTF8&psc=1

• Disinfectant wipes

https://www.amazon.co.uk/gp/product/B09YM7KJXQ/ref=ppx_yo_dt_b_asin_image_o03_s02?ie=UTF8&psc=1

• Hand sanitiser

• Tissues

• Water supply nearby (if not possible a large 2 L bottle containing water)

Annex XII: Nuclear Medicine: Separating Radionuclides Risk Assessment

RISK ASSESSMENT

Nuclear Medicine: Separating Radionuclides

Activity	Separating Radionuclides	**Demonstrator(s):**	STEM ambassador(s)
Date		**Venue:**	
Event Organiser		**Audience:**	15 – 18-year-olds and their parents / carers/ teachers
Activity Description	This activity simulates how we separate radioisotopes for their use in medical treatments and diagnostics.		

Hazards	Control Measures
Allergies	Ambassador(s): Ambassador(s) should check they are not allergic to any of the materials used for the experiment. Audience: This is a spectator activity with no major allergens, so minimal risk to the audience.
Manual handling	Ambassador(s): No heavy lifting is involved in experiments to help mitigate the risk of damage to property and person. Audience: Present in only a spectator capacity, should not be hands-on during the demonstration No heavy lifting is to be carried out and experiments carried out in the appropriate environment.
Glassware hazards (glass column)	Evacuate audience from the area. Broken glassware is to be swept up disposed of appropriately, *via* glass bin or however is specified by the venue. Appropriate PPE is worn (including safety glasses and cut-proof gloves).
Spillages	Ambassador(s) to ensure the clamp and stand are sturdy, and the column is securely attached, before preforming the activity. Should the contents of the column spill, clean it up quickly using the tissues provided. None of the contents are hazardous. The bucket provided can use used to clean the spill then dispose of the waste *via* household waste or the route approved by the venue.
Waste	If running the activity multiple times, the bucket provided can be used to store the waste after each run, before disposing of it in bulk. Dispose of the waste *via* household waste or the route approved by the venue.
General hygiene	Hand wash stations should be available or the nearest handwash point be known. Antibacterial wipes and hand sanitizer are provided.

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NATIONAL NUCLEAR LABORATORY

RISK ASSESSMENT

Hazards	Control Measures
Slips, trips and falls	Good housekeeping to be maintained to remove potential trip, slip and fall risks. This activity requires movement. Ensure there is large enough area to perform the activity and there are no hazards nearby.

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

- Appropriate ventilation and hygiene facilities should be present.

Signature: ....

Print Name: ....

Date: ....

2

NATIONAL NUCLEAR LABORATORY

Annex XIII: RADiation Robots: Handling Nuclear Waste STEM Ambassador Guide.

RADiation ROBOTS: Handling Nuclear Waste

Objectives

Students will understand the difference between legacy nuclear waste and new build nuclear waste.

They will also see the role that robots play in the clean up of nuclear waste.

Fast facts

Subject: Chemistry

Age range: 5+ years old

Ambassador preparation time: 30 minutes

Demonstration time required: 5 minutes

Location: Science Fair

Overview

Nuclear activities in the past have generated 'legacy waste'. This is very hazardous radioactive waste that we now need to handle and safely dispose of.

We need to separate this waste, but it is too hazardous for human to approach or handle- so we use robots and remote handling.

Equipment

- Multicoloured ping pong balls
- 2 x medium baskets
- Grabber arms
- Mixed wooden shapes

Links to purchase the equipment are given at the end of the guide (Equipment Purchase Links section).

Background

Radioactive waste is a controversial topic. But there is a big difference between historic legacy waste and new build waste.

Legacy waste can be defined as the radioactive waste produced during the infancy of the UK's nuclear industry, unfortunately at this time waste storage and treatment was not well managed or planned. The government is now making a greater effort to ensure this legacy waste is managed and disposed of in a manner that protects both people and the environment.

The cost of legacy waste clean up in the UK is very high. But should it condemn new build and the future of the UK's nuclear industry? The next generation of nuclear power station proposed to be built in the UK (including Hinkley point C) will be built by the private sector, with waste and decommissioning plans in place from the beginning. A funded decommissioning programme must be submitted before construction can start.

Clean up and disposal of legacy waste as quickly as possible is a priority for the government, but it has presented many unforeseen challenges that have had to be overcome by scientists and engineers.

Clean up of legacy nuclear waste has been one of the key drivers for robotics technology. Automated robots have been designed to: conduct inspections of radioactive areas with fitted cameras, enter area too hazardous for humans, retrieve radioactive samples, carry out radiation surveys, demolish buildings and monitor for contamination.

These Robots are very effective but also very expensive. The nuclear industry welcomes innovation and new ideas! One of these ideas was to utilise Master Stave Manipulators (MSMs), these sound very complicated but it's the exact same technology as a puppet arm. It's a machine that mimics your movements but at a distance, for example behind a lead wall where radioactive materials are stored. These have been used since the start of nuclear technology development and have been applied to modern solutions.

Can you think of any advantages of using a MSM over a robot?

Some answers to this question are: cost, it is much cheaper to build; maintain, mechanical components are less likely to break than electrical components; operation is easier, no computer programming is easier making it quicker to use and more versatile and training, you can train a larger range of operators more quickly.

In this activity we are going to use a robot to separate and isolate different wastes.

Method

Set up the equipment as below:

Figure 1- demonstration set-up

The demonstration is quite simple. The student will use the arm to remove the wooden shapes from the basket of 'mixed radioactive waste' and isolate it, into the empty basket. This is to demonstrate separating different types of radioactive waste before they go onto to be treated and eventually disposed of. Here the grabber is representing a Master Stave Manipulators (MSMs).

If the students are in groups, use a stopwatch to see you can remove the wooden blocks the quickest!

Figure 2- demonstration in action

At the end of the demonstration use the notes above to discuss the advantages of using MSMs instead of robot arms in the nuclear industry.

RADiation ROBOTS:
handling nuclear waste

Equipment Purchase Links

- https://www.amazon.co.uk/CURVER-245961-Storage-Tray-Medium/dp/B07ZPD3CWQ?pd_rd_w=x4DYC&content-id=amzn1.sym.ae973372-04ab-4f43-8bdd-219dc0aabb13&pf_rd_p=ae973372-04ab-4f43-8bdd-219dc0aabb13&pf_rd_r=Z7S1NM7P9XVD4RQCV8QV&pd_rd_wg=SFkXp&pd_rd_r=9d7c7fc6-69a2-4777-a7fd-3363925f9264&pd_rd_i=B07ZPD3CWQ&ref_=pd_bap_d_grid_rp_0_14_t&th=1
- https://www.amazon.co.uk/gp/product/B076WMH17S/ref=ppx_yo_dt_b_asin_image_o06_s00?ie=UTF8&th=1
- https://www.amazon.co.uk/gp/product/B0847MY7MM/ref=ppx_yo_dt_b_asin_image_o06_s01?ie=UTF8&psc=1
- https://www.amazon.co.uk/gp/product/B074Z6W7G4/ref=ppx_od_dt_b_asin_image_s00?ie=UTF8&psc=1

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Annex XIII: RADiation Robots: Handling Nuclear Waste Risk Assessment

RISK ASSESSMENT

RADiation ROBOTS: handling nuclear waste

Activity	Radiation Around Us	**Demonstrator(s):**	STEM ambassador(s)
Date		**Venue:**	
Event Organiser		**Audience:**	5 – 18-year-olds and their parents / carers/ teachers
Activity Description	This activity demonstrates the use of Master Slave Manipulators (MSMs) in the nuclear industry and discusses their use compared to robots arms.		

Hazards	**Control Measures**
Allergies	The ambassador(s) will ask any attendees if there are any allergies that they should be aware of before the activity begins.
General hygiene	Hand wash stations should be available or the nearest handwash point be known, as several people will handle the items.
Slips, trips and falls	This activity requires movement. Ensure there is large enough area to perform the activity and there are no hazards nearby. Pick up any dropped items immediately. The ambassador(s) should emphasise the importance of being aware of your surroundings.

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

- Appropriate ventilation and hygiene facilities should be present.

Signature: ....

Print Name: ....

Date: ....

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NATIONAL NUCLEAR LABORATORY

Annex XIV: Think Inside the Box: Glove Box Handling Techniques STEM Ambassador Guide.

STEM AMBASSADOR GUIDE

Think Inside the Box: Glove Box Handling Techniques

Objectives

Students will:

Learn what a glove box is and why radiochemists use them.

In a simulated` glove box participants will mix different 'solutions' of dyed water together to make a target chemical. To simulate how radiochemists handle radioactive materials and solutions.

Fast facts

Subject: Chemistry

Age range: 11+ years old

Ambassador preparation time: 30 minutes

Demonstration time required: 10 minutes

Location: Science Fair

Overview

When handling any hazardous material, we need to protect ourselves and the environment.

Radiochemists handle radioactive materials every day. Radioactive materials emit some or all of alpha, beta and gamma radiation. We have protective measure to protect lab staff from each of these forms of radiation.

Glove boxes are used to shield radiochemists from alpha radiation.

Equipment

Glove box (separate instructions attached to make the glove box if you so wish):

- Large clear plastic box (37 L)
- Rapid cure epoxy resin adhesive
- Adjustable stainless steel hose clamp
- 4-inch inner PVC plastic duct pipe
- Long length, heavy duty, chemical resistant gloves

Activity:

- 3 x 250 mL conical flask
- Food colouring (3 x primary colours)
- Squeezy plastic pipettes
- Tape

Links to purchase the equipment are given at the end of the guide (Equipment Purchase Links section).

STEM AMBASSADOR GUIDE

Glove box handling techniques

Background

Radioactive samples have three different kinds of decay: alpha, beta and gamma.

Alpha particles are from the nucleus of a radioactive atom. They consist of two protons and two neutrons and hence have a + 2 change.

Alpha particles travelling through air can be stopped by paper.

Alpha particles have the same make up as a helium nucleus (2 proton and 2 neutrons) so you will see them written as any of the below:

$$ {}^{4}_{2}\alpha^{2+} \qquad {}^{4}_{2}\mathrm{He}^{2+} $$

Beta particles are formed when a neutron splits up into a proton and an electron. You will see them written as either of the below:

$$ {}^{0}_{-1}e^{-} \qquad {}^{0}_{-1}\beta^{-1} $$

When travelling through air beta particles can be stopped by a thin layer of aluminium foil, such as the kitchen foil you'll see in your own kitchen.

Gamma waves are electromagnetic waves that come from the nucleus of a radioactive particle. They do not change the nature of the atom they come from.

They are the most penetrating type of radioactive decay and thick lead or concrete is needed to stop them. They are written as:

$$ \gamma $$

STEM AMBASSADOR GUIDE

Glove box handling techniques

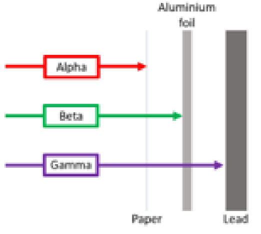

Figure 1: Alpha particles are stopped by paper, beta particles by aluminium foil and gamma rays by thick lead.

Active handling facilitates are laboratories that are licensed to handle radioactive material. They are licensed because the have the appropriate facilities in place to safely handle these materials. One of these is a glove box

Figure 2: Glove boxes at the National Nuclear Laboratory (NNL) in the UK

These glove boxes provide the researcher with physical protection from alpha radiation, as alpha particles can not penetrate the box. So, when handling any alpha emitting materials or solutions it much be done in a glove box.

STEM AMBASSADOR GUIDE

Glove box handling techniques

We are simulating a radiochemist working in a glove box in this activity.

Demonstration

If you are preparing your own glove box please see the attached instructions.

1. Fill two of the three 250 mL conical flasks with ~ 150 mL tap water.
2. Add a small amount of food dye to each conical flask. So each one is a separate primary colour, in this example we are using blue and yellow. (note only a VERY small amount of the dye is needed).
3. Place a plastic squeezy pipette into each of the two dyed solutions and place them 'into' the glove box on a slat, stable surface- likely a table. Tape the glove box down to the table to stop it from moving during the activity. The activity is very simple, the participant will put their hands into the glove box. They will then use the squeezy pipettes to mix the two dyes together and create a third colour in the empty conical flask. It may sound simple but it's harder than it looks in the glove box!

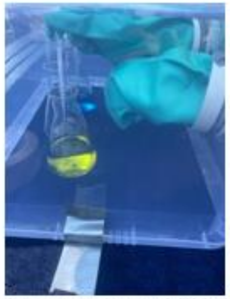

Figure 3: Glove box set up, note the tape to hold it in place on the table

STEM AMBASSADOR GUIDE

Glove box handling techniques

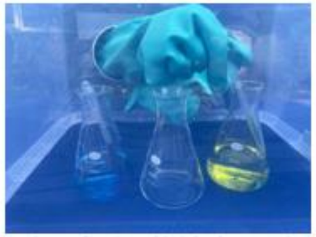

Figure 4: Glove box activity being demonstrated.

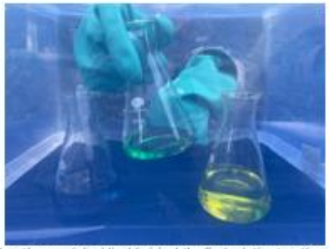

Figure 5: Here the user is 'swirling' (mixing) the final solution together. This is a lab technique we use to mix solutions together, you can demonstrate this to the students if you feel comfortable. If not they mix very well just using the pipette to stir the solution.

STEM AMBASSADOR GUIDE

Glove box handling techniques

Figure 6: an example of a user trialing the glove box activity.

Figure 7: The mixed solutions out of the box for a better view.

4. The demonstration is now complete. You can dispose of the 'mixed' solution down any sink, or bulk together for disposal at the end. Continue to use the primary colour solutions until they run out, then remake them.
5. When putting the activity away: wash and dry the glassware, store the glassware back in the bubble wrap, wash the pipettes and put back in the kit for re-use, handle the box with care as to not damage it and remove and dispose of the tape.

Equipment Purchase List with Links

- Large clear plastic box (35 L)
  - https://www.amazon.co.uk/gp/product/B001EIWQPY/ref=ppx_yo_dt_b_asin_image_o07_s00?ie=UTF8&psc=1
- Rapid cure epoxy resin adhesive
  - https://www.amazon.co.uk/gp/product/B079BX9VWG/ref=ppx_yo_dt_b_asin_image_o04_s01?ie=UTF8&psc=1
- Adjustable stainless steel hose clamp clips
  - https://www.amazon.co.uk/gp/product/B08L799Z66/ref=ppx_yo_dt_b_asin_image_o00_s01?ie=UTF8&th=1
- 4-inch inner PVC plastic duct pipe
  - https://www.amazon.co.uk/gp/product/B00YLIOWXI/ref=ppx_yo_dt_b_asin_image_o06_s02?ie=UTF8&th=1
  - https://www.amazon.co.uk/gp/product/B00YLIOWXI/ref=ppx_od_dt_b_asin_image_s01?ie=UTF8&th=1
- Long length, heavy duty, chemical resistant gloves
  - https://www.amazon.co.uk/gp/product/B089QHX78Y/ref=ppx_od_dt_b_asin_image_s01?ie=UTF8&th=1
- 3 x 250 mL conical flask
  - https://www.amazon.co.uk/gp/product/B00GDV83HC/ref=ppx_yo_dt_b_asin_image_o00_s01?ie=UTF8&th=1
- Food colouring (3 x primary colours)
  - https://www.amazon.co.uk/gp/product/B00GBLCRC6/ref=ppx_yo_dt_b_asin_image_o00_s01?ie=UTF8&th=1
- Squeezy plastic pipettes
  - https://www.amazon.co.uk/gp/product/B0838THXL2/ref=ppx_yo_dt_b_asin_image_o00_s00?ie=UTF8&psc=1
- Tape
  - https://www.amazon.co.uk/gp/product/B09HXZG8XS/ref=ppx_yo_dt_b_asin_image_o04_s00?ie=UTF8&psc=1

Annex XV: Think Inside the Box: Glove Box Handling Techniques Risk Assessment

RISK ASSESSMENT

Think Inside the Box: Glove Box Handling Techniques

Activity	Think Inside the Box: Glove Box Handling Techniques	**Demonstrator(s):**	STEM ambassador(s)
Date		**Venue:**	
Event Organiser		**Audience:**	11 – 18-year-olds and their parents / carers/ teachers
Activity Description	In a make-shift glove box participants will mix different 'solutions' (dyed water) together to make a target chemical. To simulate how radiochemists handle radioactive materials and solutions.		

Hazards	Control Measures
Allergies	Ambassador(s) should check they are not allergic to any of the materials used for the experiment. Particularly the latex gloves.
Manual handling	No heavy lifting is involved in experiments to help mitigate the risk of damage to property and person. Depending on the hight of the user the STEM ambassador may want to locate a chair from the venue. Taller participants may benefit from sitting and doing the activity, so they do not have to crouch. Smaller participants may need to stand to reach the handles of the glove box.
Glassware hazards (glass column)	Evacuate audience from the area. Broken glassware is to be swept up disposed of appropriately, *via* glass bin or however is specified by the venue. Appropriate PPE is worn (cut-proof gloves when cleaning broken glass). The box is taped to the table to prevent the glassware falling to the ground and shattering.
Spillages	Ambassador(s) to ensure the box is fastened to the table, before preforming the activity. Should the contents of the conical flasks spill, clean it up quickly using the tissues provided. None of the contents are hazardous. The waste is not hazardous and can be disposed of *via* household waste or the route approved by the venue. Liquid waste can be disposed of down any sink.
Waste	If running the activity multiple times, a bucket can be used to store the waste after each run, before disposing of it in bulk. Dispose of the waste *via* household waste or the route approved by the venue. Liquid waste can be disposed of down any sink.

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RISK ASSESSMENT

Hazards	Control Measures
General hygiene	Hand wash stations should be available or the nearest handwash point be known. Antibacterial wipes and hand sanitizer are provided.
Hazards	**Control Measures**
Slips, trips and falls	Good housekeeping to be maintained to remove potential trip, slip and fall risks. This activity requires movement. Ensure there is large enough area to perform the activity and there are no hazards nearby.

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

- Appropriate ventilation and hygiene facilities should be present.
- Due to the nature of the activity and materials used PPE is not required

Signature: ....

Print Name: ....

Date: ....

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