NTU Safety Outreach:
Biosafety and Radioactive Materials Safety

26 Jul 2018

Radioactive Material Safety

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About the Speaker

- 1998-2010 : Research chemist
- 2011- present: Research **radio**-chemist

Current Positions

1. **Lab Director**
   Rad-Nuclear Research Lab
   DSO National Laboratories (DSO)

2. **Senior Research Scientist**
   Singapore Nuclear Research & Safety Initiative (SNRSI)
   National University of Singapore (NUS)

Topics That I Will Cover Today

1. Behaviour of different types of ionizing radiation
2. Risk assessment for handling of ionizing radiation
3. Ways to Minimize Your Radiological Dose
4. Laboratory practices to avoid contamination

(5-min Intermission)

5. Responding to a Spillage
6. Wipe tests

(Tea Break)

7. Safe Guarding and Accountability for Radioactive Sources
8. Waste management

Behaviour of Different Types of Ionizing Radiation

"Know Thy Enemy"

Radiation is a Form of Energy

- Radiation is a form of energy can take the form (a) electromagnetic waves and (b) moving particles

- Importantly, radiation energy can be transferred to another material. This is one basis for safety concerns.

Non-ionizing (Low-Energy) Radiation

Non-ionizing Radiation Does Not Have Sufficient Energy to Knock Electrons Out of Atoms

- Non-ionizing radiation, is not energetic enough to knock electrons out of atoms.

- Examples of non-ionizing radiation:
  - radio waves
  - microwaves
  - infrared light
  - visible light

Radio Waves

Infra red

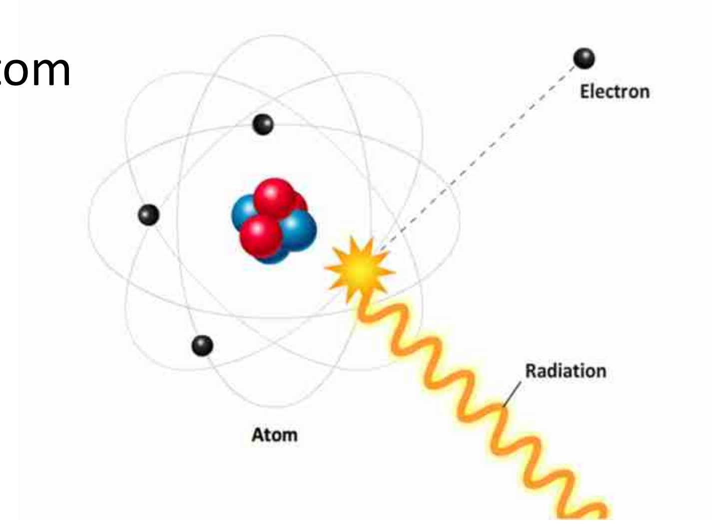
Visible Light

Micro Waves

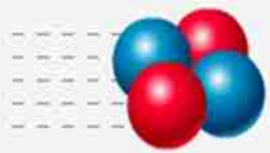
Ionizing (High-Energy) Radiation

Ionizing Radiation Knocks Electrons out of Atoms

- **Ionizing radiation** have sufficient energy to knock electrons out of atoms
  - the atom acquires a positive charge, and is highly reactive
  - the free electron travels away from the atom



4 Main Types of Ionizing Radiation



Alpha

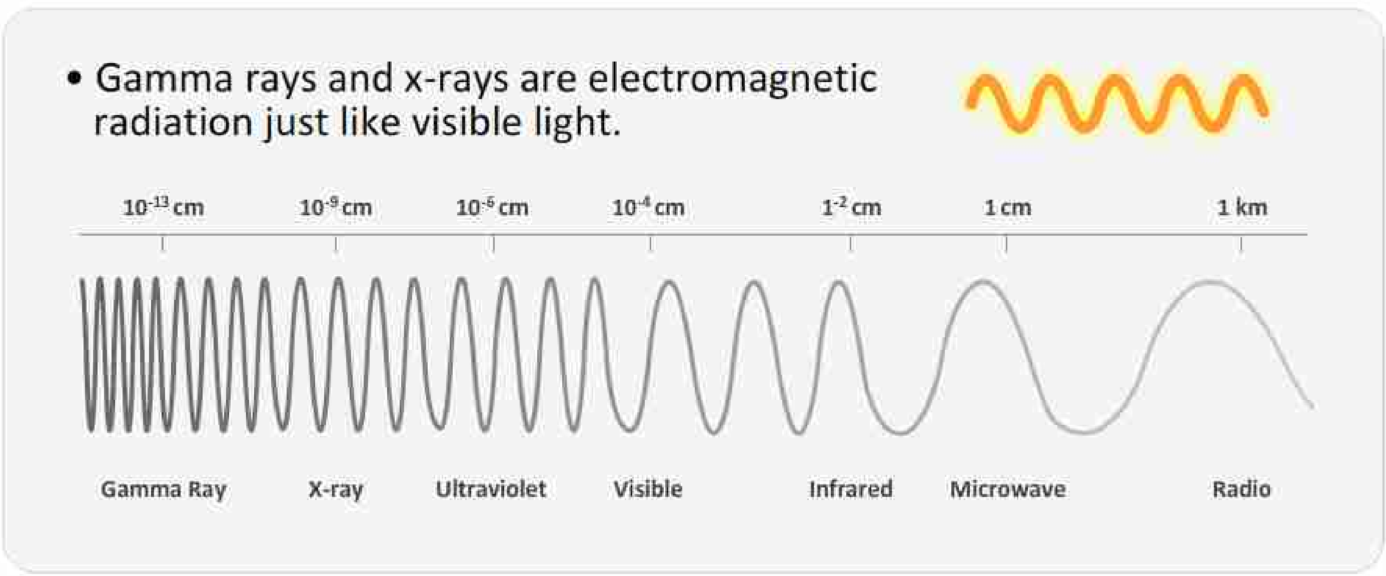
Beta

Gamma / X-ray

Neutron

Gamma Radiation

- Gamma rays are electromagnetic radiation
- They are photons, and exists as "bundles of energy"
- Highly penetrative, which probably accounts for it being most feared.



Gamma Radiation

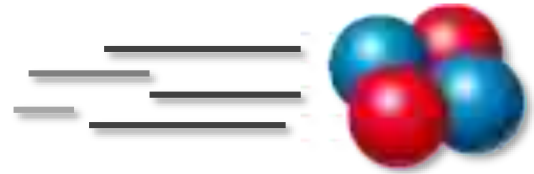
- Gamma rays are electromagnetic radiation
- They are photons, and exists as “bundles of energy”
- Highly penetrative, which probably accounts for it being most feared.

Travel up to 500 m through air

Stopped by a few cm of lead (Pb)

Penetrates body.

Alpha Radiation



- Made up of 2 protons and 2 neutrons
- Positive charge of +2
- Alpha radiation is **highly ionizing**

Travel approximately 5 cm through air

Stopped by a piece of paper.

Can’t penetrate the dead outer layer of skin.

HOWEVER, it is highly damaging when inhaled or ingested!!!

Beta Radiation

- Same mass and charge as electrons
- 8,000 times smaller than alpha particles
- Beta radiation is less ionizing than alpha radiation

Travel approximately 50 cm through air

Stopped by glass, plastic or aluminium.

Can penetrate skin and tissue to about 2mm.

- Most <u>gamma emissions</u> are accompanied by <u>beta emissions</u>

Risk Assessment (RA)
for Handling Ionizing Radiation

In radiadiological RA,

in addition to the "IF"s,

there is an important component of "HOW MUCH"

A radiological risk assessment is an estimate of the probability of a cancer over the lifetime of an exposed individual.

In Radiological RA, the Important Question to Ask is: "Is It Safe"

Examples:

"I need to handle a Cs-137 source (with activity of 1000 Bq) for 1 hour every day. Is it safe?"

"My research requires me to analyze radioactive Po-210 at a concentration of 200 Bq/L. Is it safe?"

Radiological Dose Assessment

Radiological dose assessment :
Calculates the amount of radiation energy that might be absorbed by a person, as a result of a specific activity.

External doses

- occur when the body is exposed to radioactive material outside the body
- primarily a concern for gamma radiation

Internal doses occur from exposure to radioactive **material taken into the body**

- by inhalation or ingestion
- this is a concern for alpha and beta radiation, as well as gamma radiation.

Essential Radiological Dose Assessment Terminology

Effective dose is a measure of the biological damage to the whole body resulting from exposure:

- expressed in units of Sievert (Sv)

Radiological Dose Limits

- International agencies have established recommended dose limits for both workers and the general public
- National regulations have been adopted in many countries based on these recommendations.

	IAEA	EU
General Public	≤ 1 mSv/yr	
Licensed Radiation Workers	≤ 20 mSv/yr	≤ 100 mSv over 5 consecutive yrs

"How Much is a Sievert (Sv)"

Activity	Dose (mSv)
Chest X-ray	0.1
CT scan on abdomen	10

Effects of Radiation Exposure	Dose (mSv)
Observed increase in cancer risk	100
Acute radiation sickness	1,000
50 % chance of fatality	4,000

Every 1 mSv of exposure increases cancer risk by 0.004%

Essentials of Assessing your Radiation Exposure Risk

Risk Assessment should be carried out with inclusion of at least 1 qualified and trained person:

L6 Licence holder

Example:
"I need to handle a Cs-137 source (with activity of 1000 Bq) for 1 hour every day.

Risk Assessment

RADIONUCLIDE AND RADIATION PROTECTION DATA HANDBOOK 2002

D. Delacroix*
J. P. Guerre**
P. Leblanc**
C. Hickman

Caesium - 137 / Barium - 137m

$^{137}Cs_{55}/^{137m}Ba_{56}$

Half life: 30.2 years
Specific activity: 3.20E+12 $Bq.g^{-1}$

Risk group: 1
Risk colour: Red

Main emissions (keV)	Gamma or X		Beta (Emax)		Electrons		Alpha	
	E	%	E	%	E	%	E	%
E1	32	6	512	95	624	8		
E2	36	1	1173	5	656	1		
E3	662	85			660	<1		
% omitted		<1		0		<1		

Exemption levels	
Quantity (Bq)	1E+04
Concentration ($Bq.g^{-1}$)	1E+01

Transport (TBq)	
IAEA ST1 A_1 value	2E+0
IAEA ST1 A_2 value	6E-1

EXTERNAL EXPOSURE ($mSv.h^{-1}$) for an activity of 1 MBq or 1 $MBq.m^{-2}$ (as appropriate)

Point source (30 cm)

Betas, electrons (skin dose): 2.13E-1

Gammas, X rays (deep tissue dose): 1.07E-3

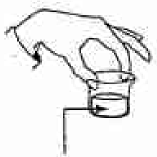
Infinite plane source

Betas, electrons (skin)	
10 cm	9.0E-02
1 m	6.0E-03
Photons (skin)	
10 cm	3.9E-03
1 m	2.5E-03
Photons (deep dose)	
10 cm	3.7E-03
1 m	2.4E-03

10 ml glass vial

9.19E-5

Contact with 50 ml glass beaker



3.30E-1

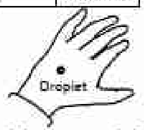
Contact with 5 ml plastic syringe

1.66E+0

The values above do not include Bremsstrahlung radiation.

CONTAMINATION

Contamination skin dose ($mSv.h^{-1}$)	
Uniform deposit (1 $kBq.cm^{-2}$)	1.57E+0
0.05 ml droplet (1 kBq)	7.08E-1



Detection: Recommended probes*	
Alpha	
Beta	++
Gamma	++
X rays	++

Derived limits ($Bq.cm^{-2}$)
Removable contamination
4E+1
Fixed contamination
4E+3

* If no probes are indicated the recommended technique is to use a wipe test in association with a probe or liquid scintillation technique

SHIELDING (mm)

Betas and electrons (Total absorption)	
Glass	4.1
Plastic	5.8

Gamma and X rays (half and tenth value thickness)	½	$^1/_{10}$
Lead	8	24
Steel	29	72

INTERNAL EXPOSURE FOR WORKERS

COMMITTED EFFECTIVE DOSE PER UNIT INTAKE ($Sv.Bq^{-1}$)

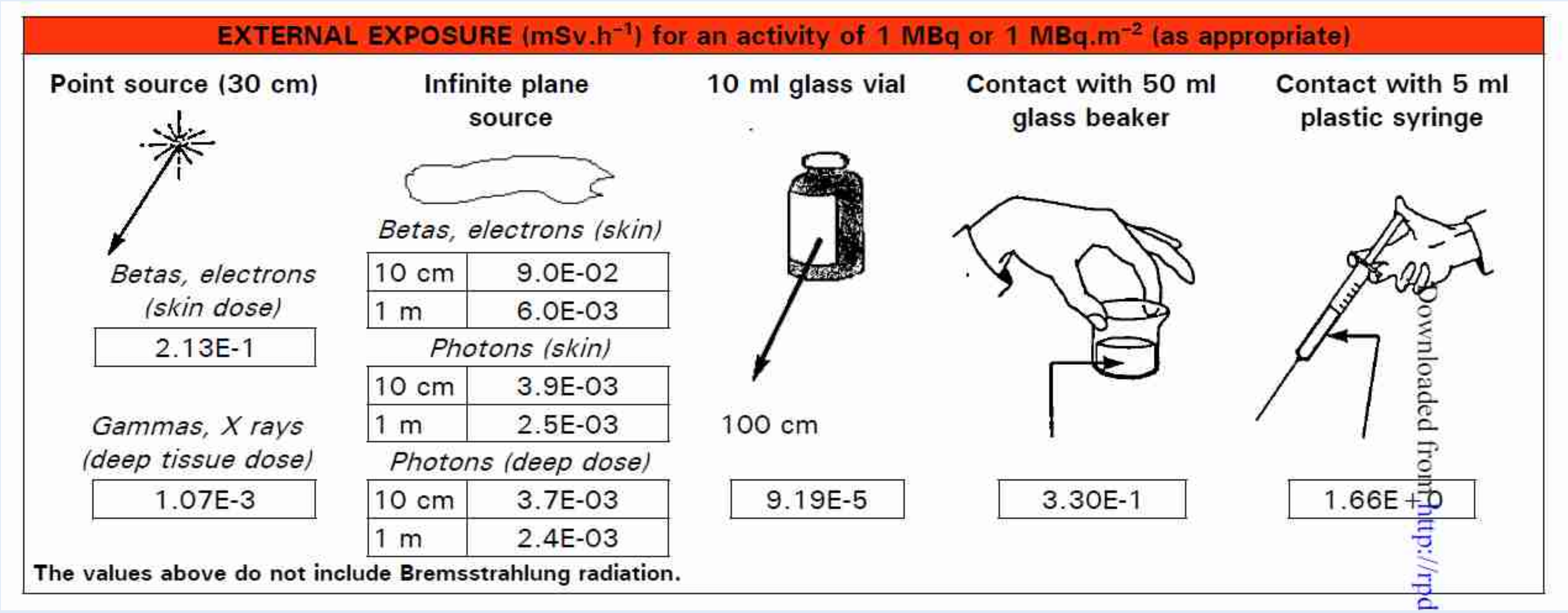
Ingestion	f_1		Inhalation		1 µm	5 µm
All compounds	1.000	1.3E-08	All compounds	F	4.8E-09	6.7E-09
				M		
				S		

Highest dose organ: Soft tissues — 20 mSv $ALI_{ingestion}$: 1.5E+06 (Bq) — 20 mSv $ALI_{inhalation}$: 3.0E+06 (Bq)

MAXIMUM RECOMMENDED ACTIVITIES IN LOW LEVEL OR INTERMEDIATE LEVEL LABORATORIES (Bq)

PHYSICOCHEMICAL STATE	Volatility factor (k)	Supervised area: Bench	Supervised area: Fume hood	Controlled area: Bench	Controlled area: Fume hood	Controlled area: Glove box
All compounds	0.01	2E+05	2E+06	8E+05	8E+06	5E+08

Subject to external exposure requirements which may be more restrictive


EXTERNAL EXPOSURE (mSv.h^{-1}) for an activity of 1 MBq or 1 MBq.m^{-2} (as appropriate)
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Photons (skin)
10 cm 3.9E-03
1 m 2.5E-03
Photons (deep dose)
10 cm 3.7E-03
1 m 2.4E-03
10 ml glass vial
100 cm
9.19E-5
Contact with 50 ml glass beaker
3.30E-1
Contact with 5 ml plastic syringe
1.66E+0
The values above do not include Bremsstrahlung radiation.

Common Misunderstandings

Health Hazards of Alpha Particles

"Alpha particles can't even penetrate our skin. There is no need to worry about them".

Dose Contribution of Beta Particles

"Cs-137 is a gamma emitting isotopes. The health risk is gamma rays only."

Ways to Minimize Your Radiological Dose

I love my family. I love my life.

I take responsibility for my own safety.

I always apply ALARA to ensure I stay safe.

Make constant efforts at all times to keep radiological doses to "As Low As Reasonably Achievable".

This is commonly called the **ALARA** principle.

6 Simple Ways to Lower Your Radiological Exposures

1. Plan your work with ALARA in mind.

- Have you exhausted all reasonable ways to reduce the potential exposure? E.g.
  - can I substitute with stable isotopes?
  - can I reduce the radioactivity?
  - is there a more sensitive measurement instrument that I can use?

2. Plan to Spend the Least Possible Time with the Sources.

- Plan for a productive experimental approach. E.g.
  - bracketing approach
  - “measure twice, cut once” to avoid wasted experiments
  - consider rehearsing the procedure (also avoids accidents)

6 Simple Ways to Lower Your Radiological Exposures

3. Consider using Tongs to Hold the Sources.

- Dose decreases rapidly with distance
- However, weigh it against higher probability of dropping the source

Handling with tongs.

4. Store Away Rad Sources, Properly Shielded if Necessary

A lead pig.

Lead bricks.

6 Simple Ways to Lower Your Radiological Exposures

5. May Consider using Pb-lined Aprons and Radiation Shields.

Lead-lined apron.

Lead glass.

- Pb-lined aprons may slow you down and increase your exposure time – so seek a balance. Beware of ergonomic risk too.

6 Simple Ways to Lower Your Radiological Exposures

6. Consider Carrying a Digital Dosimeter.

A **digital dosimeter** provides real time alerts when high dose rates are detected.

Summary: 6 Simple Ways to Lower Your Radiological Exposures

1. ALARA always in mind and in practice.

2. Spend the Least Possible Time with the Sources.

3. Tongs to Hold the Sources.

4. Store Away Rad Sources.

5. Consider Pb-lined Aprons and Radiation Shields.

6. Carry a Digital Dosimeter.

Bonus #7. Always Practice Contamination Control Measures.

Laboratory Practices to Avoid Contamination

Contamination: *"Having undesirable substances at places you wish they weren't there."*

Contamination can:

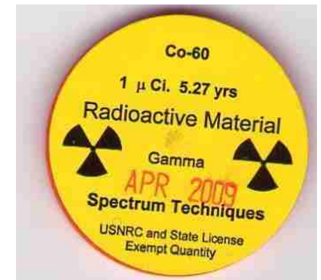
- lead to unnecessary radiological doses
- cause loss-of-use of equipment
- confound your experimental data

Avoidance of Contamination Pays!
And it does not take a lot to avoid contamination.

Sealed and Unsealed Sources

Sealed Sources

- the radioactive material is permanently sealed in a capsule or bonded in a solid form
- the radioactive material should not escape/released during normal usage



A Co-60 sealed source

Un-sealed Sources

- the radioactive material is not encapsulated or otherwise contained
- the radioactive material can move around, and if uncontrolled, would lead to contamination

An unsealed liquid source

Types of Contamination

1. **Personal Contamination**
   - external
   - internal

2. **Facility Contamination**
   - fume hood, lab bench
   - lab

3. **Equipment / Instrument Contamination**

5 Simple Ways to Avoid Contamination

1. Use Sealed Sources instead of Unsealed ones (if possible).

Sealed sources has no contamination risk.

Avoid using unsealed sources.

2. Wear Personal Protection Equipment. Always.

- **Use impermeable lab coat e.g. polypropylene**
- Protective eyewear

- Consider double gloving when handling high radioactivity
- Consider taping up glove closure around wrist
- Consider glove box for handling high activity sources

Polypropylene lab coat.

5 Simple Ways to Avoid Contamination

3. **Cover Work Surfaces with Adsorbent Sheets e.g. BenchGuard™**

Adsorbent sheets.

5 Simple Ways to Avoid Contamination

4. Screen for Contamination.

- Screen for personal contamination using **hand-and-foot radiation monitor**
- Screen for work surface contamination using **survey meters**

A hand-and-foot radiation monitor.

A cost-effective survey meters

5 Simple Ways to Avoid Contamination

5. Cover Equipment / Instrument with a Thin Plastic Sheet

A survey meter protected by thin plastic cover.

A gamma spectrometer protected by thin plastic sheet.

Summary: 5 Simple Ways to Avoid Contamination

1. Use Sealed Sources
2. Wear PPE. Eye Protection is Important.
3. Cover Working Surfaces with Adsorbent Sheets.
4. Screen for Contamination.
5. Cover Equipment / Instrument with a Thin Plastic Sheet.

5 min intermission

Responding to a Spillage

Unless you are dealing with very hot sources, the spillage is unlikely to be life-threatening.

Response to spillage shall not risk persons getting contaminated.

Immediate Concerns & Response

1. Stay Calm & Decide Course of Action

- inhalation is a big concern if aerosolisation is a possibility
  - *hold your breath when near the source*
- the situation can worsen if you act rashly e.g. removing your PPE in a manner to contaminate your skin
- Is the radiation beyond acceptable limits (e.g. 10 uSv/h) to respond immediately .
  - If yes, proceed as with Step 2
  - If no, contain the spread using paper towel; retreat and organize a mitigation team.

Immediate Concerns & Response

2. Step Up Radiation Protection Posture

- Wear respiratory protection
- Beta exposure may become significant
  - Use tongs and maintain an arm's length distance

3. Protect the Facility from Further Contamination

- Contain the spillage as much as possible
  - throw in some paper towels as soon as you can

Recovery from the Spillage

1. **Clean Up**
   - Using tongs, wipe and soak up with sorbent towel and dispose into rad-waste bag
     - wipe <u>inwards</u> to prevent spreading of contamination
     - tongs are now contaminated

   - If possible, dispose of contaminated articles e.g. pipettes

2. **Decontaminate**
   - Use decontaminant (e.g. RadiacWash^{TM}) to clean up contaminated surfaces

Recovery from the Spillage

3. Survey

- Ensure decon was successful by using surface survey meter and/or wipe test

4. Conduct a Dose Assessment

- Seek medical advice if deemed necessary
- Report to Regulatory Agency i.e. NEA

Wide-Spectrum Decontaminant

RadiacWash™

- Allows contamination to be rinsed away with water
  - sequester metallic ions
  - lifts up and suspends contaminating particles

- Can use on practically any surfaces, including skin

Wipe Tests

What is a wipe test?

- a method to detect the undesirable presence of <u>transferrable</u> radioactive materials

- also used to detect low-level contamination

Why perform wipe tests?

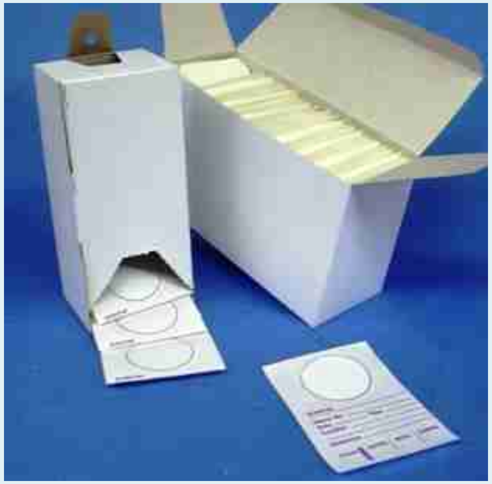
- to check for leakage or breakage of sealed sources
- the integrity of the sealed sources is the primary basis of its safety

It is a regulatory requirement to perform wipe test for sealed sources, at least once every 12 months .

Check for Leakage or Breakage of Sealed Sources

How to Perform a Wipe Test?

- simply wipe the surface with swab several times
- measure radioactivity on the swab



Use Wipe Test to Detect Low-Level Contamination

Some suspect areas

- Working surfaces
- Door knobs
- Water taps
- Door handle of the lab oven, refrigerator, cabinets etc
- Bottle caps of chemical reagents
- Telephone !

Tea Break

Safe Guarding and Accountability for Radioactive Sources

In general, radioactive sources are hazardous to people and our environment.

Fell into the wrong hands, they can be used for malicious intent.

Requirements by Singapore Radiation Protection Acts

A book containing a record of the following information must be maintained:

- date of receipt
- nature and form of the radioactive material
- radioactivity of the radioactive material
- the whereabouts of the radioactive material, kept up to date on each working day

- for **sealed sources**
  - (i) a distinguishing number
  - (ii) date and the manner of disposal of the sealed source

- For **unsealed sources**
  - (i) the quantity used each time and the date and purpose of use
  - (ii) the date and manner of disposal, or any portion of it

Accountability and Traceability

The record book shall reflect the real-time inventories and whereabouts of all the radioactive sources.

Accountability and Traceability

How the record may look like for a sealed source:

Source ID: 61283	**Date Was Received :** 18 Aug 2017			**Isotope and activity** Co-60 (1 mCi)		
S/N	**Draw Out**			**Return**		
	Date	By	Sign out	Date	Verified by (L6)	Sign in
1.	2018-2-17	Joseph Lee	[illegible]	2018-3-2	Ellen See	[illegible]
2.	2018-7-25	Eugene Tan	[illegible]			

Accountability and Traceability

How the record may look like for an unsealed source:

<table>
<tr><td colspan="2">Source ID:
8417</td><td colspan="3">Date Was Received :
29 Sep 2013</td><td colspan="3">Isotope and activity
Pu-238(20.2 Bq /g), 50mL</td></tr>
<tr><td rowspan="2">S/N</td><td colspan="4">Draw Out</td><td colspan="3">Disposal</td></tr>
<tr><td>Date</td><td>By</td><td>Mass</td><td>Sign out</td><td>Date</td><td>Disposal reference</td><td>Verified by (L6)</td></tr>
<tr><td>1.</td><td>2013-10-26</td><td>Lily Tan</td><td>5.452 g</td><td></td><td>2018-3-2</td><td>NEA-20142214</td><td></td></tr>
<tr><td>2.</td><td>2015-11-02</td><td>May Lee Hwi</td><td>7.034 g</td><td></td><td></td><td></td><td></td></tr>
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Safe Guarding: Securing the Rad Sources

Recommended to have 2 types of storage for radioactive sources:

(1) Highly-controlled

- Stores all sources that are not in use currently
- Only L6 should have access

(2) Limited-access

- Stores sources that are being used by staff on a daily basis
- Could be a safe with key or PIN access
  - practical for daily securing of rad sources

Annual Stock-Taking

- Purpose: Part of process detect lost rad sources
    - also keeps everyone on their toes

- Effective to conduct the annual **wipe tests** together with the annual stock-taking

Waste Management

The best waste management approach is to **minimize waste generation.**

Especially when it comes to radioactive waste.

Don't be faced with the situation that you can't dispose the waste and have to store it. Indefinitely.

General Principles for Rad Waste Management

1. Minimize the generation of Rad Waste
   - Use as low concentration as possible (in line with ALARA)
   - Be efficient e.g. achieve same quality of research output with as few experiments as possible

2. Segregate the wastes based on (a) isotopes and (b) level of activity

   - Affect waste storage methods
   - Affect waste disposal costs
   - Short-lived isotopes – store for sufficiently long time to be treated as normal waste

Exemption Levels for Radio-isotopes

- Below defined quantities, radioactive sources are exempted from requirements for notification, registration or licensing
  - In other words, they are not under regulatory control

- One criterion for exemption is that <u>the radiation risks of that source are sufficiently low</u> to warrant any benefits of regulatory control.

Rad Waste or Non-rad Waste?

	Material and Scenario	Type of Waste	
		For Sources Below Exemption	For Sources Above Exemption
1.	Pipette tips	Non-rad	Rad
2.	Gloves – no suspect of contamination	Non-rad	Rad
	Gloves – possibly contaminated	Non-rad	Rad
	Gloves – contaminated	Rad	Rad
3.	Filters paper	Non-rad	Rad
4.	Solutions containing rad materials e.g. ICP-MS samples	Rad	Rad
5.	Vials previously used to contain the rad material e.g. used ICP-MS vials	Non-rad	Rad

Storage of Liquid Waste

- Liquid waste can cause wide-spread contamination, and so is not an ideal waste form

- Immobilize the liquid waste by mixing it with exfoliated Vermiculite
  - Vermiculite is a hydrous phyllosilicate mineral
  - After being exfoliated by heat, Vermiculite is light weight, has high water retention and high cation exchange capacity

Exfoliated Vermiculite.

RADIATION PROTECTION ACT
(CHAPTER 262, SECTION 28)
RADIATION PROTECTION (IONISING RADIATION) REGULATIONS

CAP. 262, Rg 2] *Radiation Protection (Ionising Radiation) Regulations* [2001 Ed. p. 1

RADIATION PROTECTION ACT
(CHAPTER 262, SECTION 28)

RADIATION PROTECTION (IONISING RADIATION)
REGULATIONS

https://sso.agc.gov.sg/SL/RPA1991-RG2#pr27-