Radiation Safety Training

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Outline

- Module 1 : Regulations and Licensing
- Module 2 : Basic radiation Physics
- Module 3 : Radiation and Risks
- Module 4 : Detection Instruments
- Module 5 : Transport and Handling
- Module 6 : Working in Laboratories

MODULE 1 : Regulations and Licensing

Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

http://www.cnsc-ccsn.gc.ca

The Canadian Nuclear Safety Commission

An Overview

Nuclear safety is everyone's business. Every day, millions of Canadians use nuclear energy, though we may not always be aware of how it contributes to our lives.

The Canadian Nuclear Safety Commission (CNSC) regulates the use of nuclear energy and materials to protect health, safety, security and the environment and to respect Canada's international commitments on the peaceful use of nuclear energy. Created in 1946 as the Atomic Energy Control Board, the agency changed its name in 2000 with the enactment of the *Nuclear Safety and Control Act* (NSCA). Its vision is to be one of the best nuclear regulators in the world by being effective, efficient, transparent and an employer of choice.

Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

CNSC Mission

To regulate the use of nuclear energy and materials to protect health, safety, security and the environment and to respect Canada's international commitments on the peaceful use of nuclear energy.

Canadian Nuclear Safety Commission

Commission canadienne de sûreté nucléaire

CNSC Mandate

Under legislation enacted by Parliament, and policies, directives and international commitments of the federal government, we:

- regulate the development, production and use of nuclear energy in Canada;
- regulate the production, possession, use and transport of nuclear substances, and the production, possession and use of prescribed equipment and prescribed information;
- implement measures respecting international control of the development, production, transport and use of nuclear energy and nuclear substances, including measures respecting the non-proliferation of nuclear weapons and nuclear explosive devices; and
- disseminate scientific, technical and regulatory information concerning the activities of the CNSC, and the effects on the environment, on the health and safety of persons, of the development, production, possession, transport and use of nuclear substances.

Regulatory & Licensing Information

Acts, Regulations and By-laws

The Nuclear Safety and Control Act (NSC Act) came into force on May 31, 2000, when it replaced the Atomic Energy Control Act. It provides the Canadian Nuclear Safety Commission with its regulatory authority.

Under the NSC Act, the Commission has put in place a number of regulations and bylaws. Electronic versions of the key regulations and bylaws administered by the CNSC can be found below.

Regulations

- Canadian Nuclear Safety Commission Rules of Procedure (PDF)
- General Nuclear Safety and Control Regulations (PDF)
  - Office Consolidation (PDF)
- Radiation Protection Regulations (PDF)
- Class I Nuclear Facilities Regulations (PDF)
- Class II Nuclear Facilities and Prescribed Equipment Regulations (PDF)
- Uranium Mines and Mills Regulations (PDF)
- Nuclear Substances and Radiation Devices Regulations (PDF)
- Packaging and Transport of Nuclear Substances Regulations (PDF)
  - Office Consolidation (PDF)
- Nuclear Security Regulations (PDF)
- Nuclear Non-Proliferation Import and Export Control Regulations (PDF)
- CNSC Cost Recovery Fees Regulations (HTML) (PDF)

Bylaws

- Canadian Nuclear Safety Commission By-laws (PDF)

Regulations and Licensing

Canadian Nuclear Safety Commission (CNSC)

“The mission of the Canadian Nuclear Safety Commission (CNSC) is to regulate the use of nuclear energy and materials to protect health, safety, security and the environment and to respect Canada's international commitments on the peaceful use of nuclear energy.”

Regulations and Licensing

The Canadian Nuclear Safety Act

- Defines Nuclear Energy Workers & Nuclear Facilities
- Establishes the Canadian Nuclear Safety Commission (CNSC)
  - Defines duties, powers and responsibilities
  - Ability to make regulations and issue licenses
  - Defines powers of inspectors
  - Defines "opportunity to be heard"
- Establishes penalties for offenses and noncompliance
- Defines Canada's participation in international safeguards treaty

Regulations and Licensing

- The CNSC is the "**Court of Record**"
  - May issue summons or administer oaths
  - Not bound by legal rules
  - Its decisions become rules of Federal Court.
- CNSC inspectors may enter and inspect at any reasonable time.
  - May search without a warrant
  - May order any measures to protect the environment or safety of persons.
  - Every person must give reasonable assistance

Regulations and Licensing

Offences and Punishments defined in the act.

- Failure to assist inspector

  ($5000 or 6 months)
- Misuse of safety equipment
- Failure to comply with license condition, act or any order
- Falsification of records
- Failure to report for duty (!)
- Possession of nuclear material that may be used to make nuclear explosive device

  (10 years)

CNSC Regulations (Rad. Protection)

The CNSC regulations define:

- Obligations of licensees and Nuclear Energy Workers (NEWs)
- Radiation dose limits
- Dosimetry services
- Labelling and signs
- Records to be kept

CNSC Regulations (General)

Obligation of Licensees :

- Ensure presence of qualified staff
- Train workers to carry out activities in accordance with the act
- Take reasonable precautions to protect environment and health and safety of persons
- Maintain devices within specifications
- Take all reasonable precautions to prevent release of radioactive material

CNSC Regulations (Rad. Protection)

Obligations of Licensees :

- Every licensee shall implement a radiation protection program to:
  - Keep the exposures As Low As Reasonably Achievable (ALARA)
  - Ascertain the quantity and concentration of release of radioactivity
  - Ascertain and record the doses to radiation workers

CNSC Regulations (General)

Obligation of Workers :

- Comply with procedures in a responsible and reasonable manner
- Comply with measures established to protect environment and health and safety of persons
- Promptly inform supervisor of:
  - Increase in risk
  - Threat to security
  - Failure to comply with act, regulations or license
  - Any act of sabotage or theft of nuclear substance
  - Unauthorized release of radioactive substance
- Observe and obey all notices and warnings
- Take all reasonable precautions for own safety and of safety of others

Regulations and Licensing

A Nuclear Energy Worker

In the Canadian Nuclear Safety Act a nuclear energy worker is defined as:

"a person (worker) who is required, ... , to perform duties in such circumstances that there is a reasonable probability that the person may receive a dose of radiation that is greater than the prescribed limit for the general public."

CNSC Regulations (Rad. Protection)

Obligations of Nuclear Energy Workers (NEWs) :

- Every nuclear energy worker shall, on request by the licensee, inform the licensee of the workers:
  - Given names, surname and previous surnames
  - Social Insurance Number
  - Sex
  - Date, province and country of birth
  - Dose record for the previous one-year and five-year dosimetry periods

CNSC Regulations (Rad. Protection)

Pregnant Nuclear Energy Workers :

- Every NEW who becomes aware that she is pregnant shall ***immediately*** inform the licensee ***in writing.***
- On being informed by a NEW that she is pregnant, the licensee shall, in order to comply with section 13 (dose limits) make any accommodation what will not occasion costs or business inconvenience constituting undue hardship to the the licensee.

Regulations and Licensing

The CNSC Regulations define limits on effective dose.

Person	Period	Effective Dose (mSv)
Nuclear Energy Worker (Including a pregnant NEW)	One-year dosimetry period	50
	Five-year dosimetry period	100
Pregnant NEW	Balance of the pregnancy	4
A person who is not a NEW	One calendar year	1

Regulations and Licensing

The CNSC Regulations define limits on equivalent dose.

Organ or Tissue	Person	Period	Equivalent Dose (mSv)
Lens of an eye	NEW	One-year dosimetry period	150
	Any other person	One calendar year	15
Skin	NEW	One-year dosimetry period	500
	Any other person	One calendar year	50
Hands and feet	NEW	One-year dosimetry period	500
	Any other person	One calendar year	50

Regulations and Licensing

These limits may be exceeded if there is a life threatening emergency, BUT

-Effective dose must remain less than 500 mSv
-Equivalent dose (skin) must be less than 5000 mSv

CNSC Regulations (Nuclear Substances)

Prescribed Nuclear Substances are defined as quantities of radioactivity greater than the **Exempt Quantities** listed in schedule 1 of the act

10 kBq, for Z<81

10 kBq, for Z>81
But:
Not α-emitter and
No short-lived α-emitting progeny

500 Bq, for Z>81
And:
α-emitter or
short-lived α-emitting progeny

Not more than 10 sources per year

Exempted Quantities <u>are not</u> regulated.

Exempted Quantities

A license is NOT required to :

Possess, transfer, import, export, use, mine, produce, refine, convert, enrich, process, reprocess, manage or store a nuclear substance, if the quantity of the nuclear substance does not exceed its **exemption quantity (NSRDR 5.1)**

CNSC Regulations (Nuclear Substances)

Radioactive material that is used on site is required to have the following documentation:

- Name, quantity, form and location
- Model and serial number (sealed sources)
- Quantity used
- Manner in which it is used
- Name of each worker who uses or handles
- Record of transfer, receipt, disposal or abandonment
- **Record of training of each worker (for 3 years)**
- Record of all inspections, measurements and tests

MUHC Licenced Activities

- **Nuclear Substances and Radiation Devices**
  - Nuclear Medicine (diagnostic)
  - Nuclear Medicine (therapeutic)
  - Gammacell Irradiator (self-shielded type)
  - Consolidated Activities (Research)
- **Class-II Equipments**
  - Brachytherapy
  - Cobalt Teletherapy
  - Accelerators
  - Calibration

Regulations and Licensing

For Nuclear Substances Licensing :

- MUHC has one contact person at the CNSC, J.-C. Poirier
- The CNSC has one contact person at the MUHC, C. Janicki, RSO/NSRD.

For Class II Equipment Licensing :

- MUHC has one contact person at the CNSC, A. Licea
- The CNSC has one contact person at the MUHC, M. Evans, RSO/Class II.

MODULE 2
Basic radiation physics

A Brief History

- **X-rays were first observed in 1895 by A.H. Roentgen**
  - On the 8th of November, he covers with a black strong paper an apparatus that he uses to study electricity phenomena
  - The screen placed nearby seems shining some green light
  - His hand placed behind the screen shows the shadow of his hand-bones!
  - At the end of December, he publishes a short article, claiming for a fantastic news: the existence of an unknown and strange radiation, that is thus quickly named "X rays".
  - For this discovery, he receives the **first physics Nobel price in 1901**.

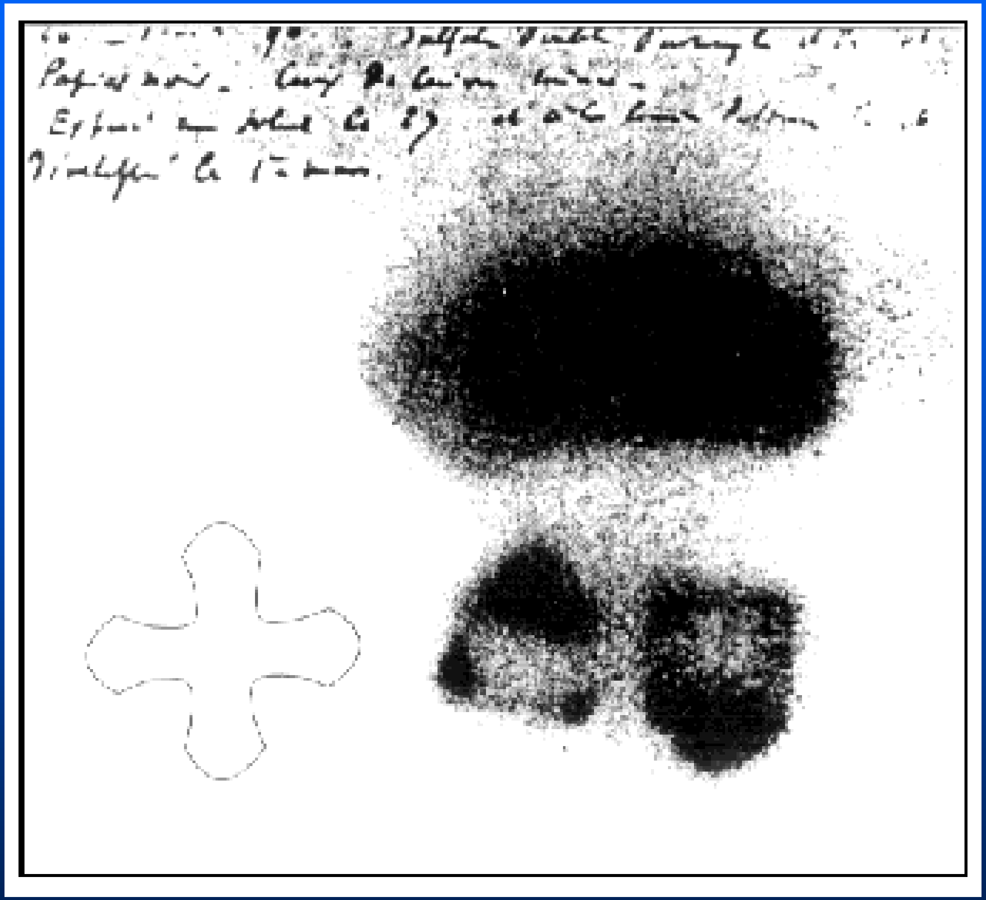
Roentgen discovers X-Rays

A.H. Roentgen

Roentgen's wife hand
with wedding ring

A Brief History

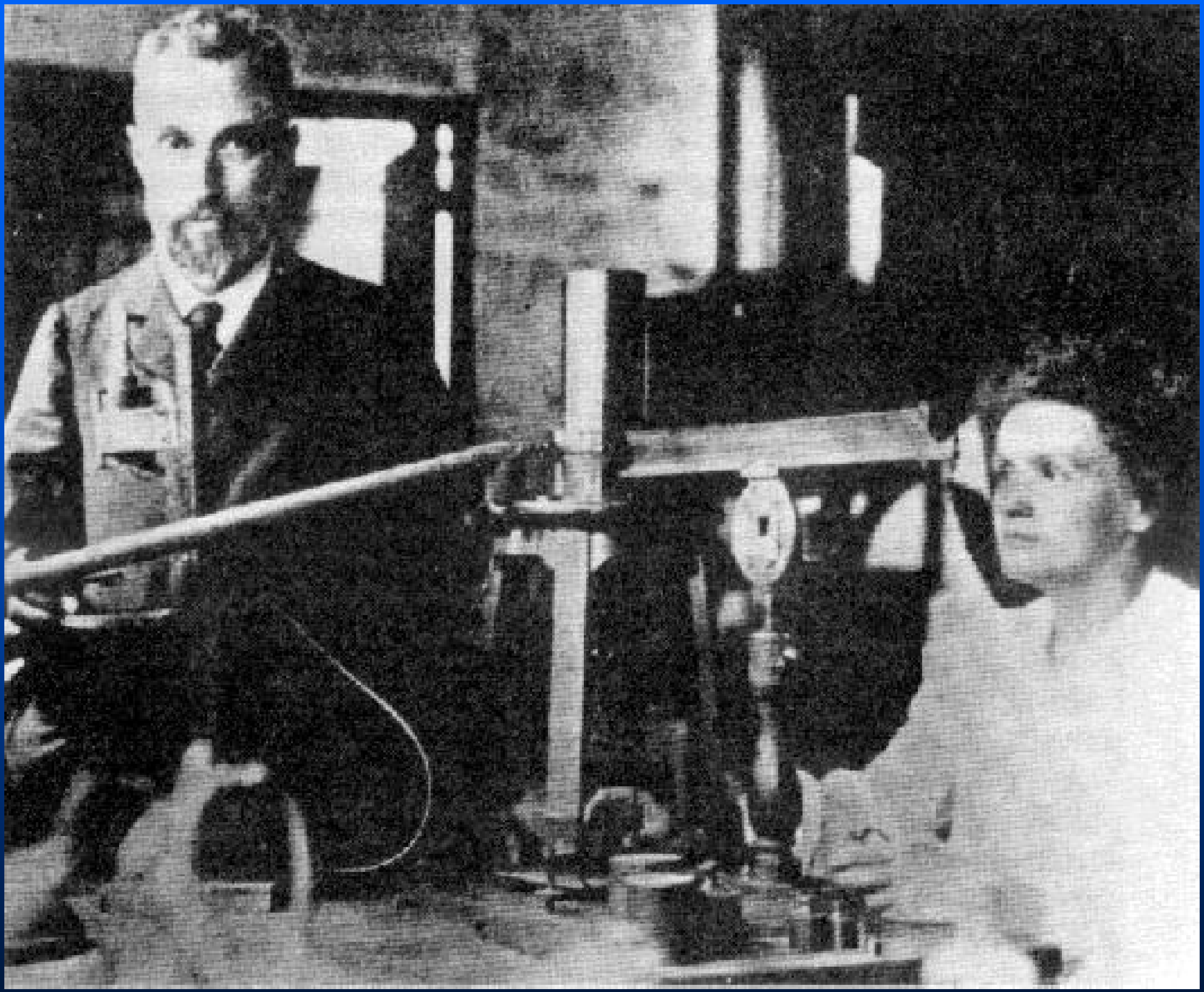
- **Radioactivity was first observed in 1896 by A. H. Becquerel**
  - salts of uranium are brought into the vicinity of an unexposed photographic => the plate becomes exposed
  - uranium salts also causes a charged electroscope to discharge
  - the salts exhibit phosphorescence and are able to produce fluorescence



Photographic plate of Becquerel impressed by the radioactivity of uranium.

A Brief History

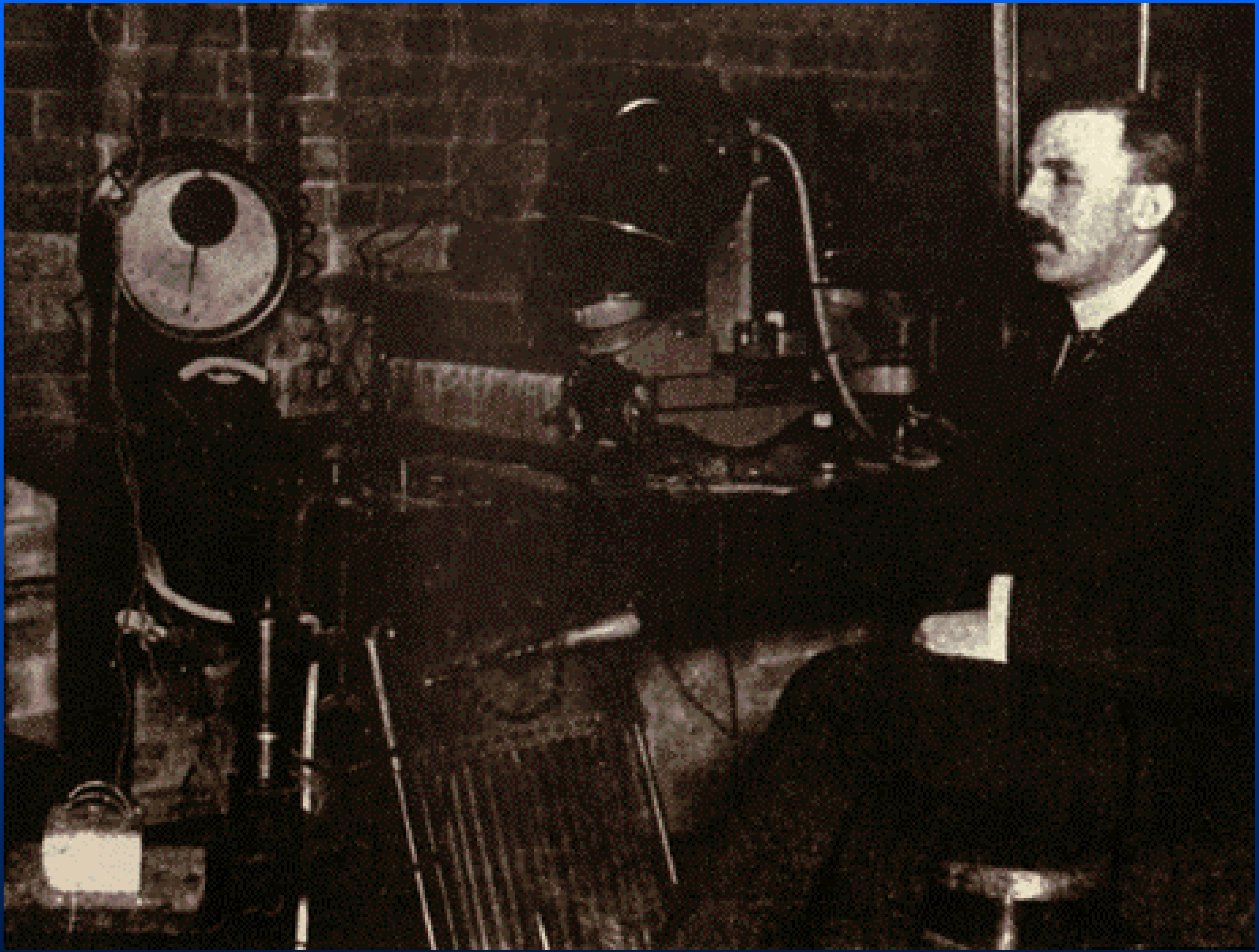
- **Marie and Pierre Curie extended the work on radioactivity**
  - Demonstrate the radioactive properties of thorium
  - Isolate a new material 1 000 000 times more radioactive than uranium : “polonium”
  - In 1898, from penchblende ore (many tons!), they extract by hand some milligrams of an other new material, 2 500 000 times more radioactive than uranium: the “radium”
  - They receive the Nobel price of Physics in 1903 for the discovery of radium
  - Marie Curie received the Nobel price of Chemistry in 1911 for chemistry works on radium



Marie and Pierre Curie

A Brief History

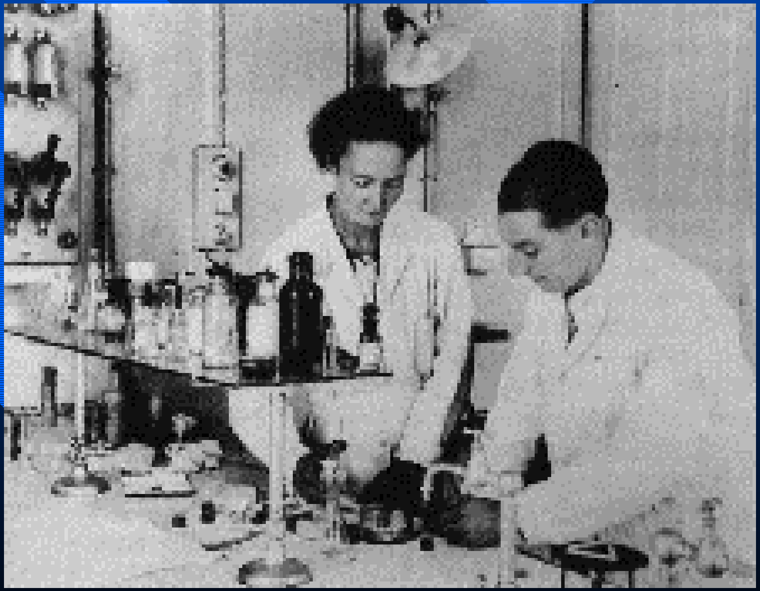
- E. Rutherford
  - Discovers alpha and beta radiation in 1899
  - The first to elucidate the related concepts of the half-life and decay constant
  - With Frederick Soddy at McGill University, Rutherford showed that elements such as uranium and thorium became different elements (i.e., transmuted) through the process of radioactive decay
  - For this work, Rutherford won the 1908 Nobel Prize in chemistry.



Ernest Rutherford in his Laboratory at McGill University, Ca. 1903

A Brief History

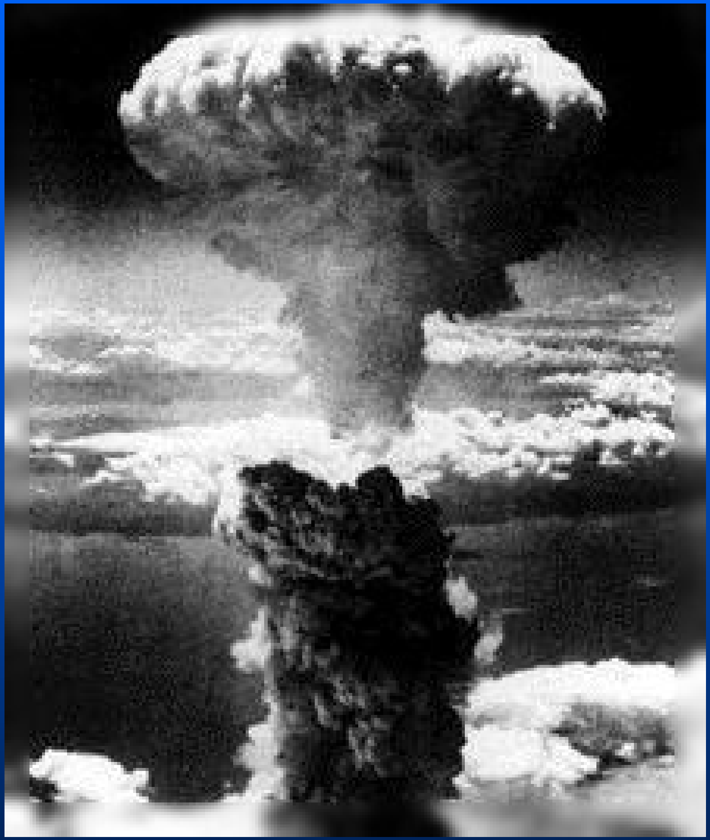
- Frédéric and Irène Joliot-Curie discovered the first example of artificial radioactivity in 1934 by bombarding nonradioactive elements with alpha particles
  - By shooting an aluminium sheet with alpha particles (helium nuclei), they were able to make radioactive phosphorus



A Brief History

- On July 4, 1934 Leo Szilard filed a patent application for the atomic bomb
- December 1935, Chadwick won the Nobel Prize for discovery of the neutron.
- January 13, 1939 - Otto Frisch observed fission directly by detecting fission fragments in an ionization chamber.
- January 29, 1939 - Robert Oppenheimer hears about the discovery of fission and realized that it might be possible to build a bomb.
- Manhattan Project began on September 17, 1942 led by R.O.

In 1945, we enter the NUCLEAR AGE



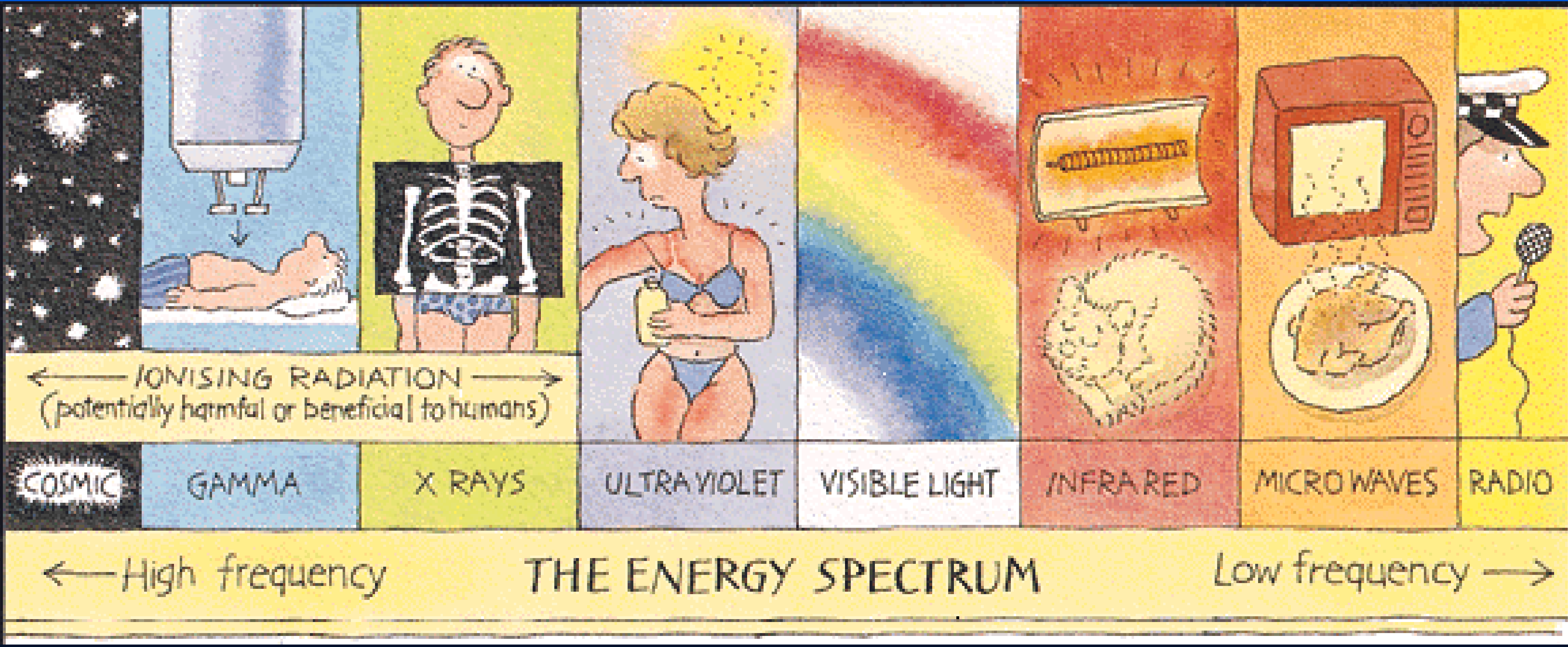
On July 16, 1945, Oppenheimer witnessed the first explosion of an atomic bomb in the New Mexico desert.

"We knew the world would not be the same" R.O.

What is Radiation ?

Radiation:

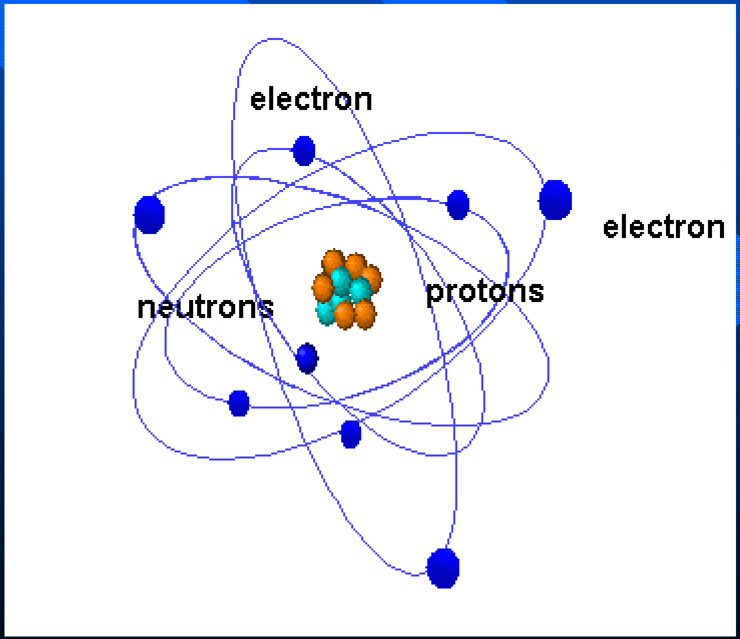
The transmission of energy through space in the form of waves or streams of particles.



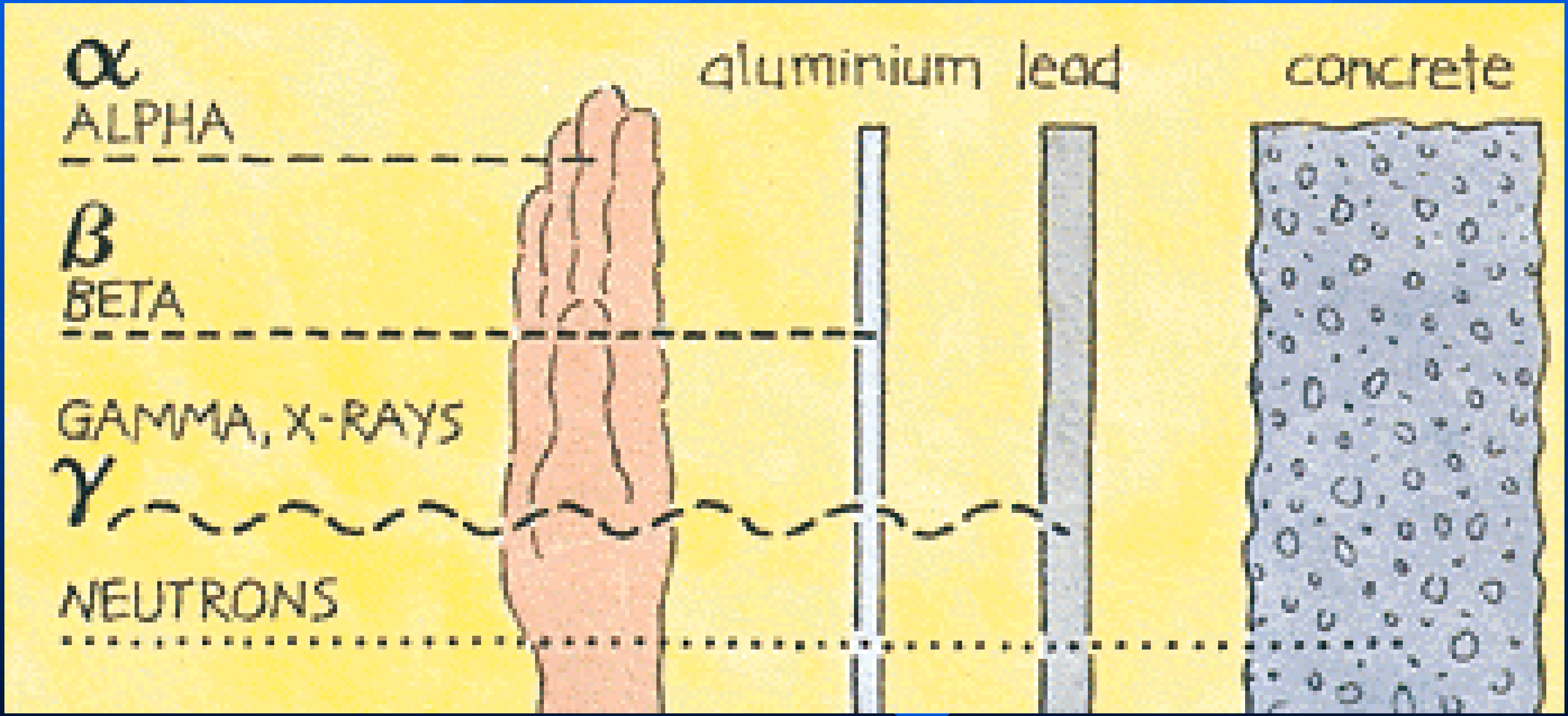
What is Ionizing Radiation?

Ionizing Radiation

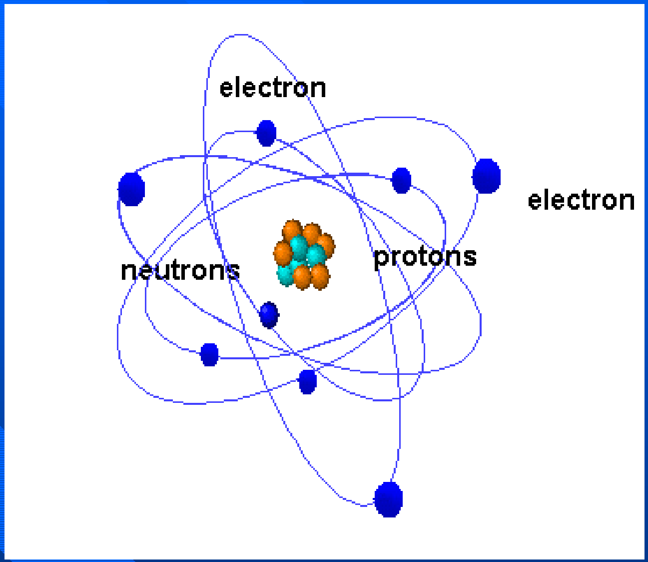
Radiation that has sufficient energy to ionize, or remove electrons from, an atom.



Types of Ionizing radiation

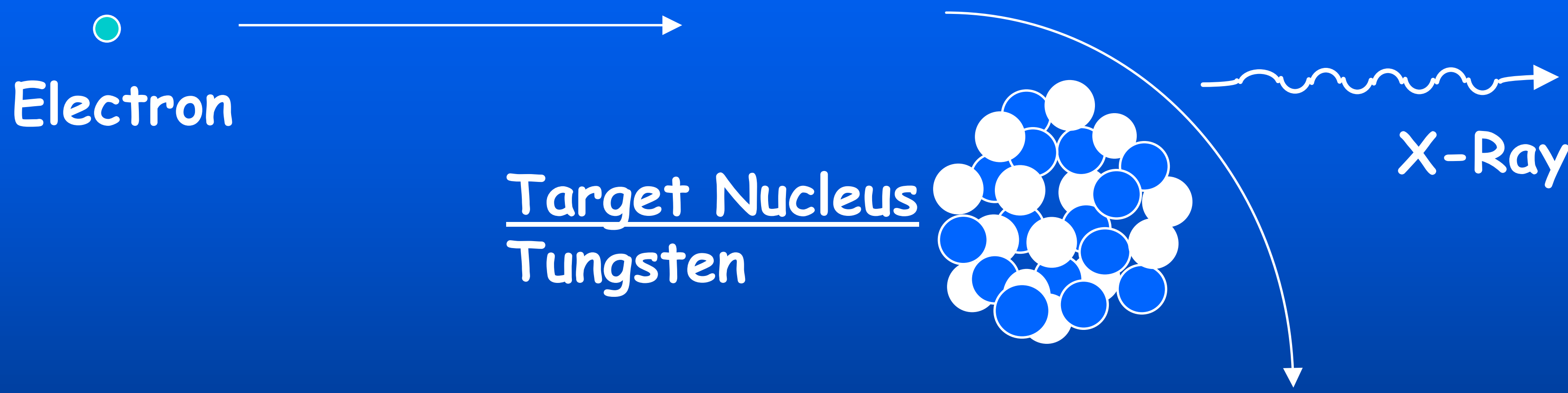


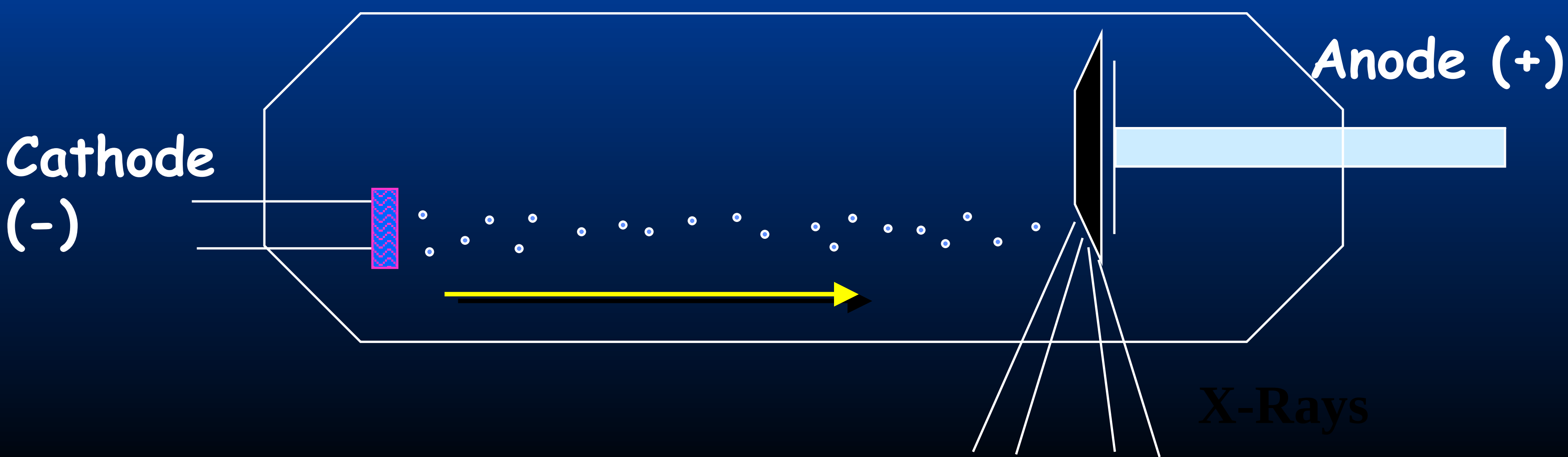
Types of Ionizing radiation



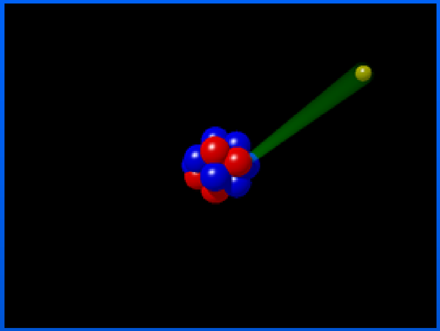
- Orbital Electrons
  - X-Ray emission
- Nuclear Decay
  - gamma emission
  - beta (electron, positron) emission
  - alpha particles
  - neutrons

X-Ray Production (Bremsstrahlung)





Nuclear Decay and Radioactivity



WHAT IS NUCLEAR DECAY ?

spontaneous transformation of an unstable combination of nucleons (PARENT) to a less unstable combination of nucleons (DAUGHTER)

WHAT IS RADIOACTIVITY ?

spontaneous emission of particulate and/or electro-magnetic radiation

Units of Radioactivity

Radioactivity is measured in Bequerels (Bq)

- 1 bequerel (1Bq) = 1 transformation/second
- 1 megabequerel (1MBq) = 10^6 transformations/sec
- 1 gigabequerel (1GBq) = 10^9 transformations/ sec

The Bequerel has recently replaced the Curie as the SI unit of radioactivity:

1 curie = number of transformations/sec/g radium
= 3.7×10^{10} transformations/second
= 37 GBq (large!)

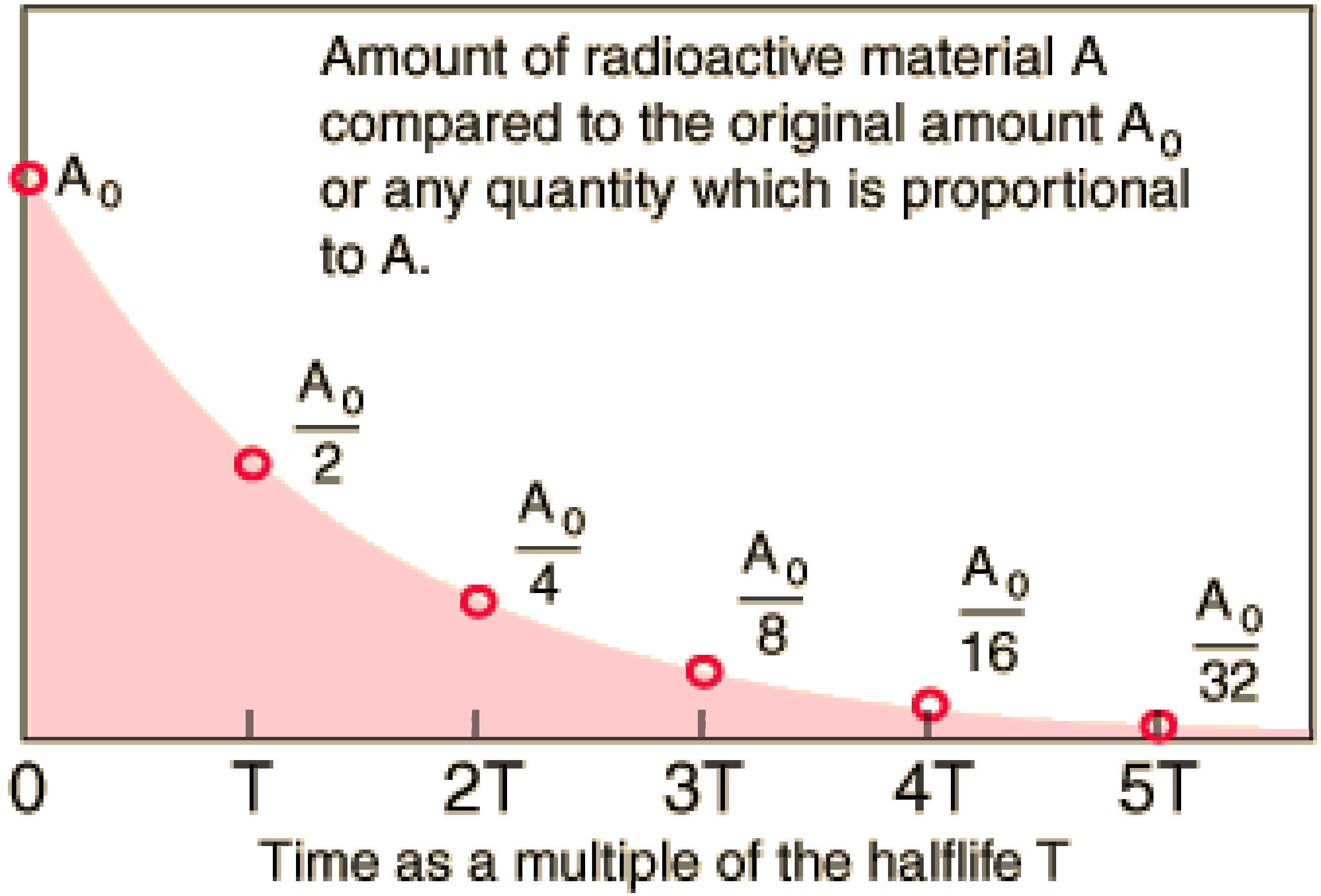
Decay and Half-lifes

- Radioactive decay is governed by laws of probability (quantum mechanics)
- Nucleus X will "probably" decay during time interval Δt with probability $p(\Delta t)$
- For Δt infinite, $p = 1$
- The time for $p = 0.5$ is the half-life $T_{\frac{1}{2}}$

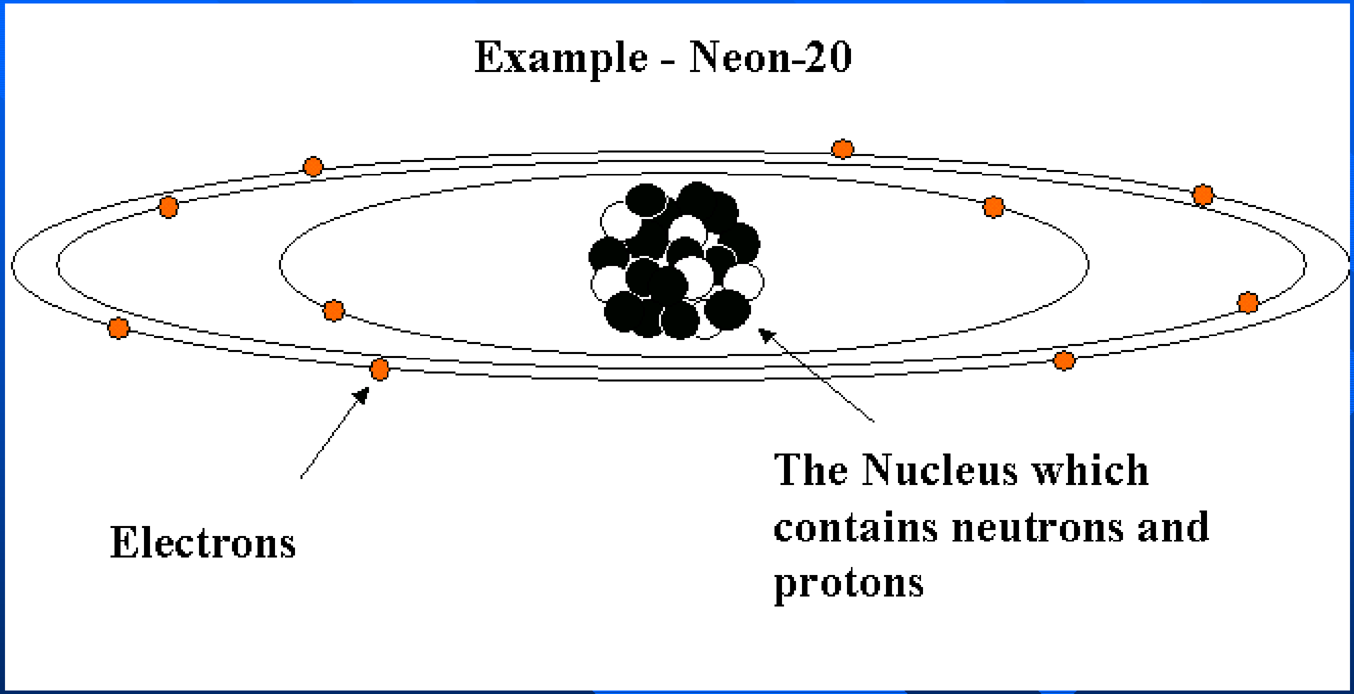
Decay and Half-lifes

$$A = A_0 2^{\frac{-t}{T_{1/2}}}$$

$$= A_0 e^{\frac{-.693\, t}{T_{1/2}}}$$



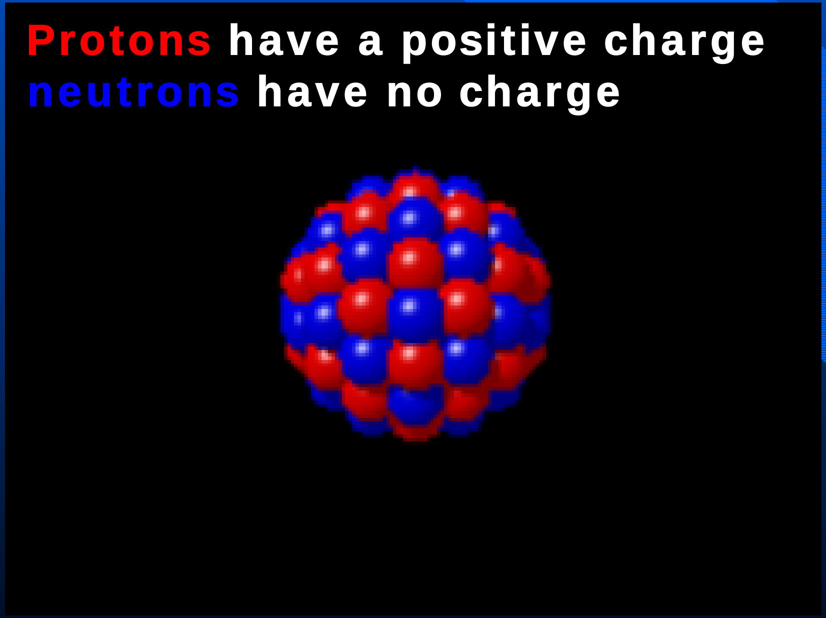
Basic Nuclear Theory

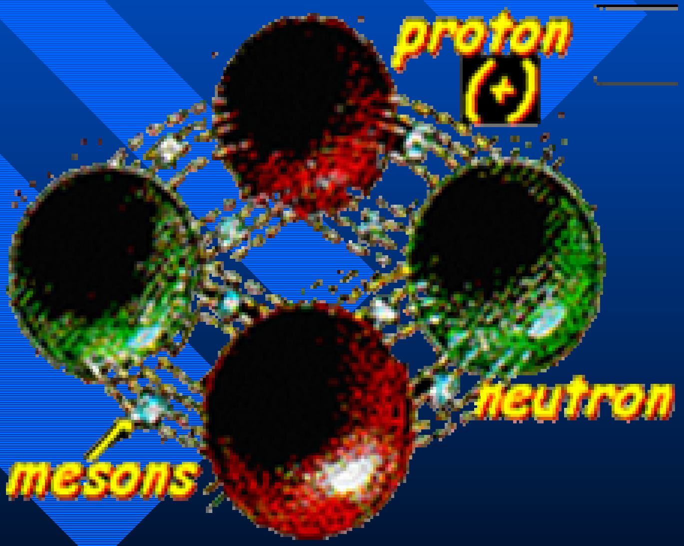


An Atom contains Protons, Neutrons and Electrons

Basic Nuclear Theory

- The nucleus is composed of **neutrons (n)** and **protons (p)**
- **n** and **p** are bound together by mesons





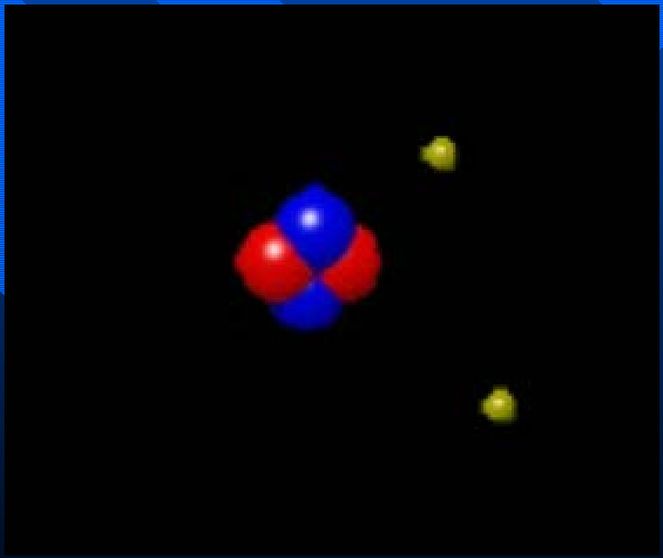
Basic Nuclear Theory

The **number of protons** in the nucleus is known as the atoms **atomic number Z**

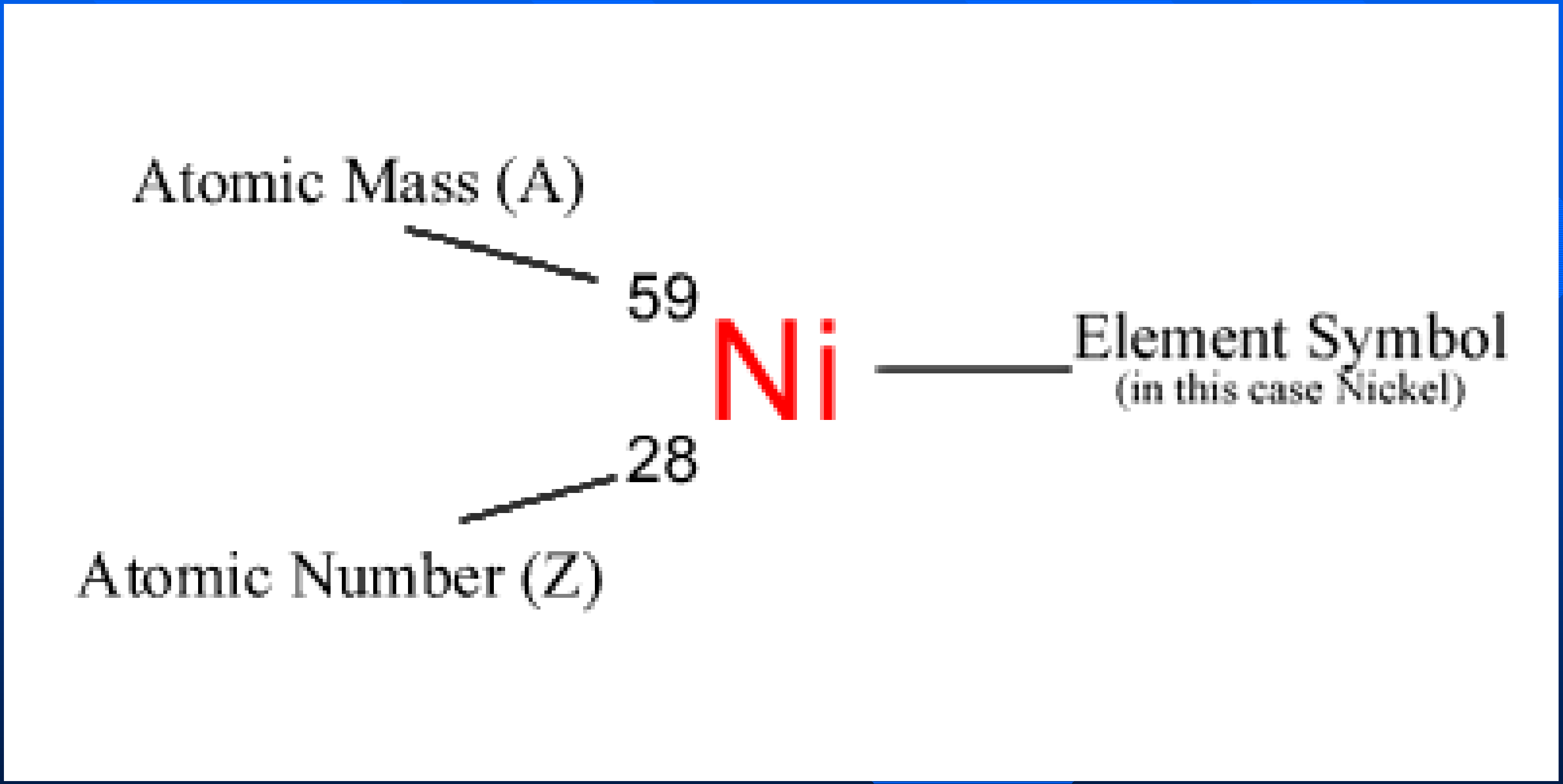
The total number of particles (p + n) in the nucleus is called the atoms **atomic mass A**

Example : He atom

Z = 2
N = 2
A = N + Z = 4

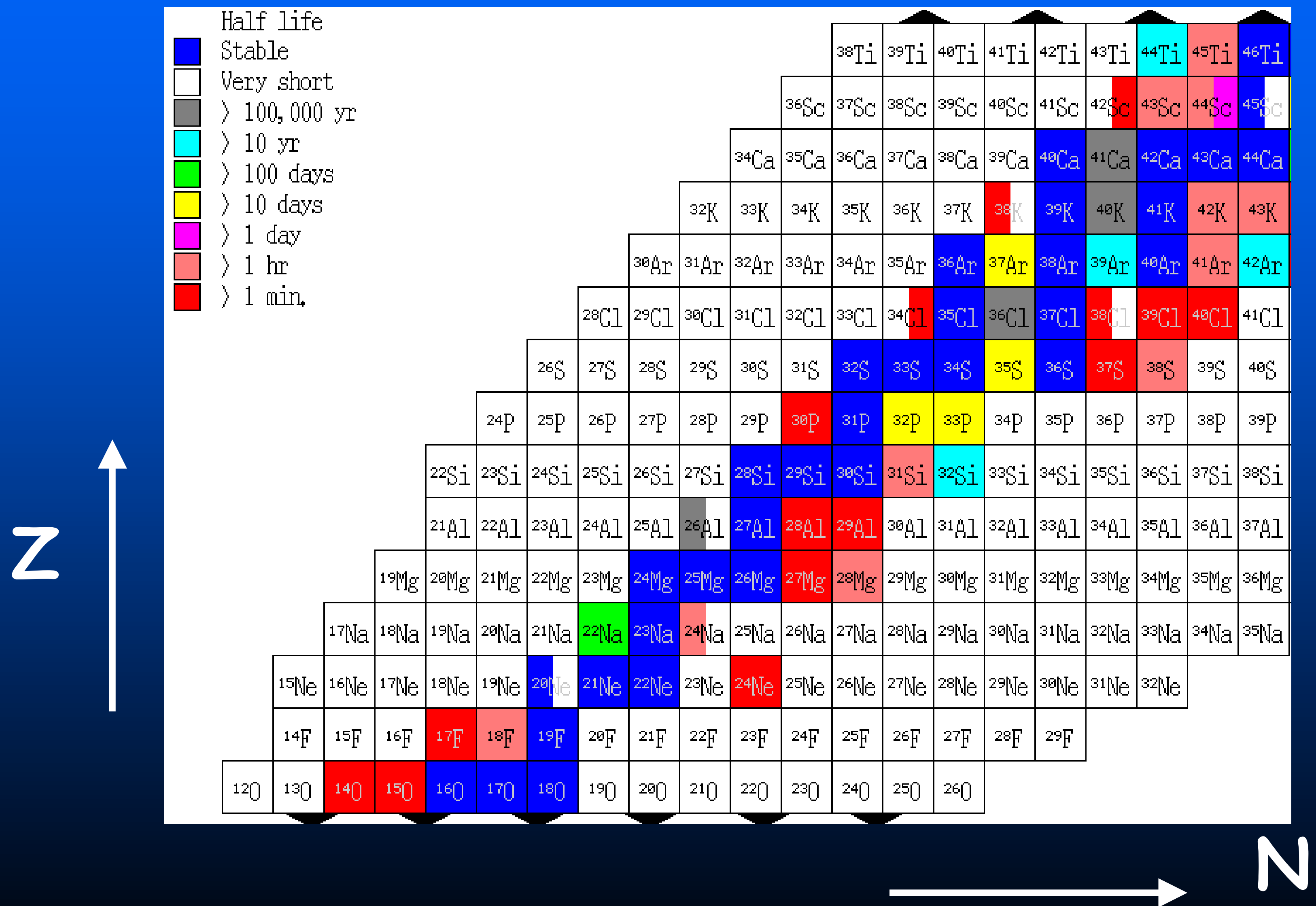


Notation



Atomic Mass (A)
59
Ni
Element Symbol
(in this case Nickel)
28
Atomic Number (Z)

Chart of the Nuclides



Nuclear Families

Isotopes : Same number of protons Z

Different number of neutrons N

Z	7	8	9	10	11	12	13	14	15
8	O -218.79° -182.95° -118.56° -2 15.9994 0.078%	O16 0+	O17 1/2+	O18 0+	O19 4 s 3/2+ β-	O20 8 m 0+ β-	O21 800 ms 3/2+ β-	O22 10 s 0+ β-	O23 300 ms 1/2+ β-

N

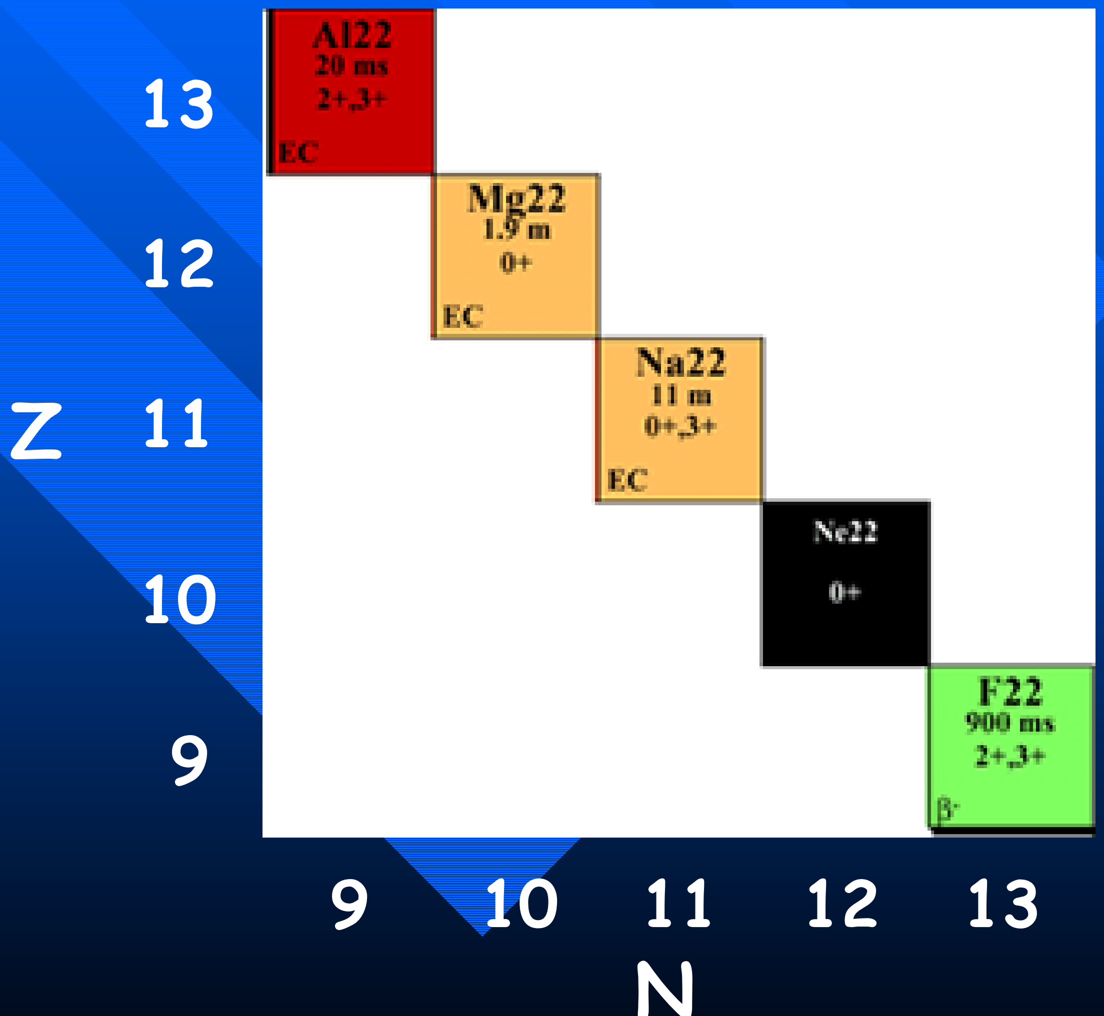
Nuclear Families

Isotones :

Same neutron number N

Nuclear Families

Isobars : Same mass number *A*



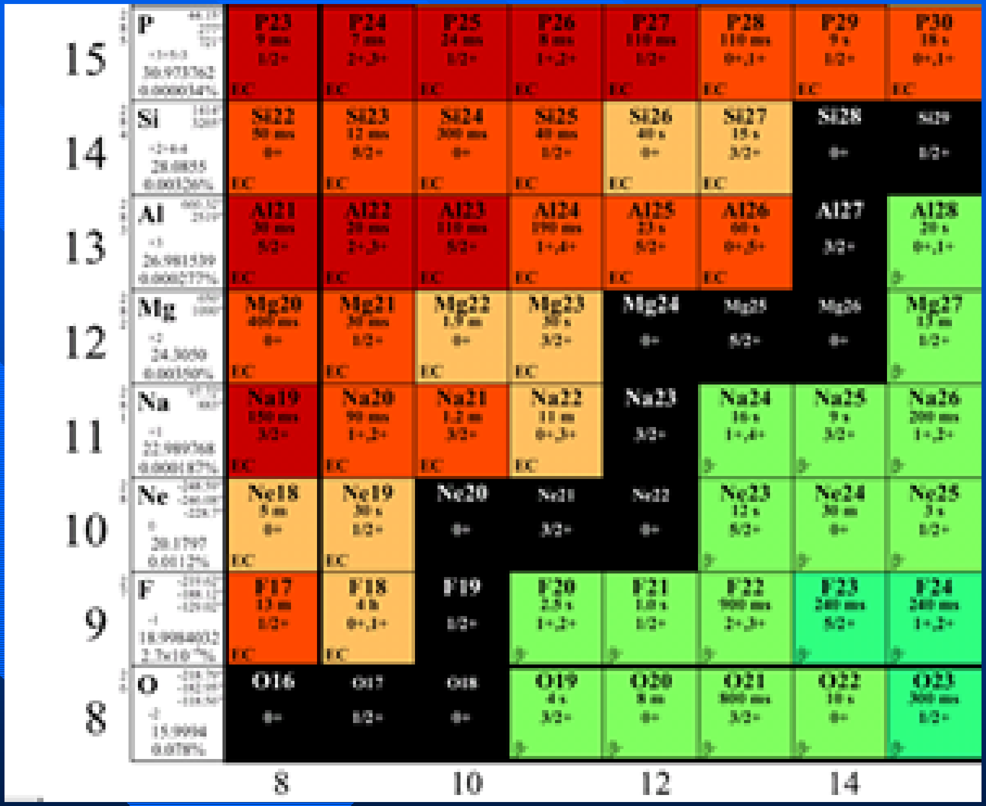
Line of Stability

Long-lived nuclides are close to the line of stability

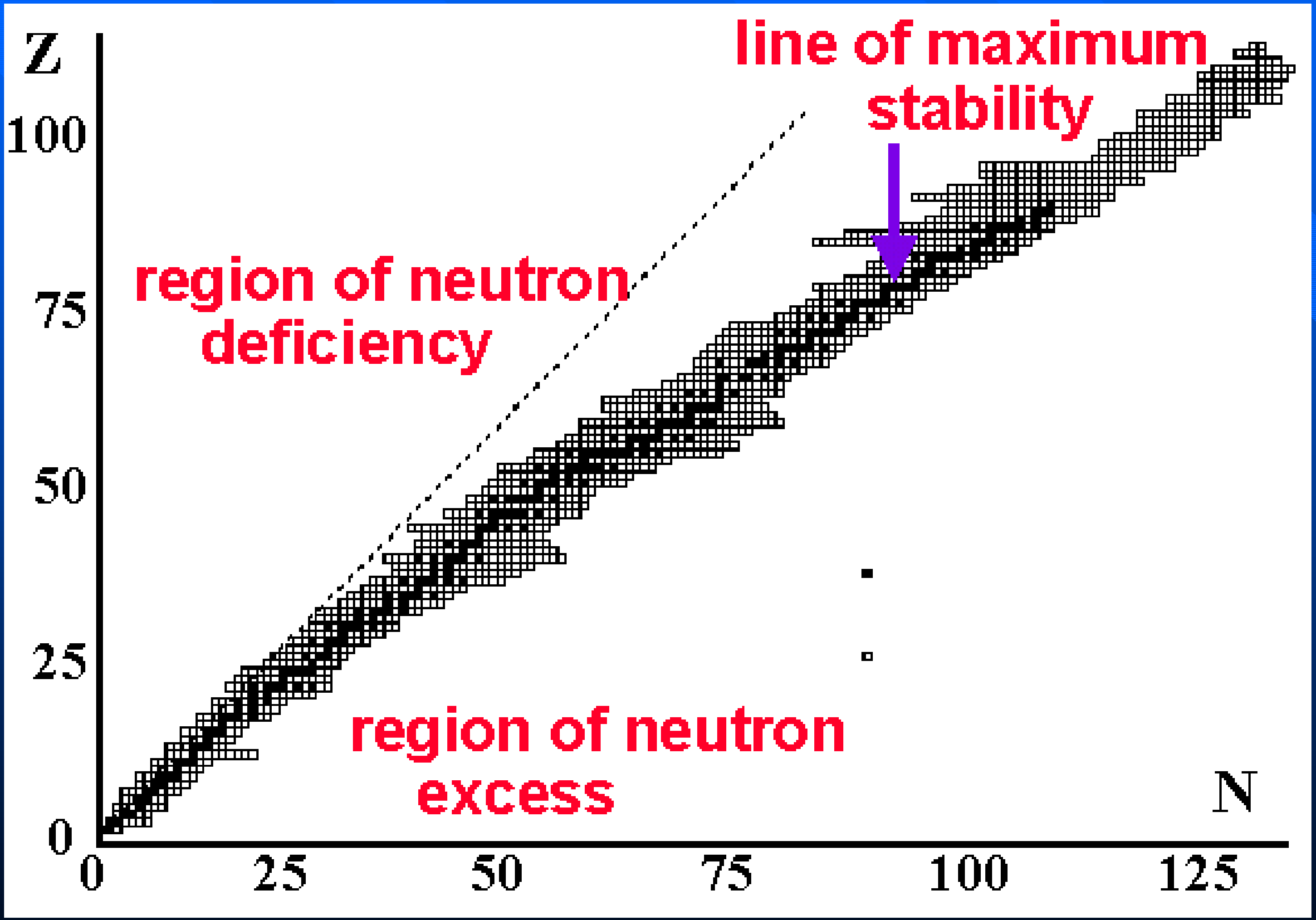
The half-life gets shorter the further away from the line

Excess Proton => above the line

Excess neutron => below the line



Line of Stability



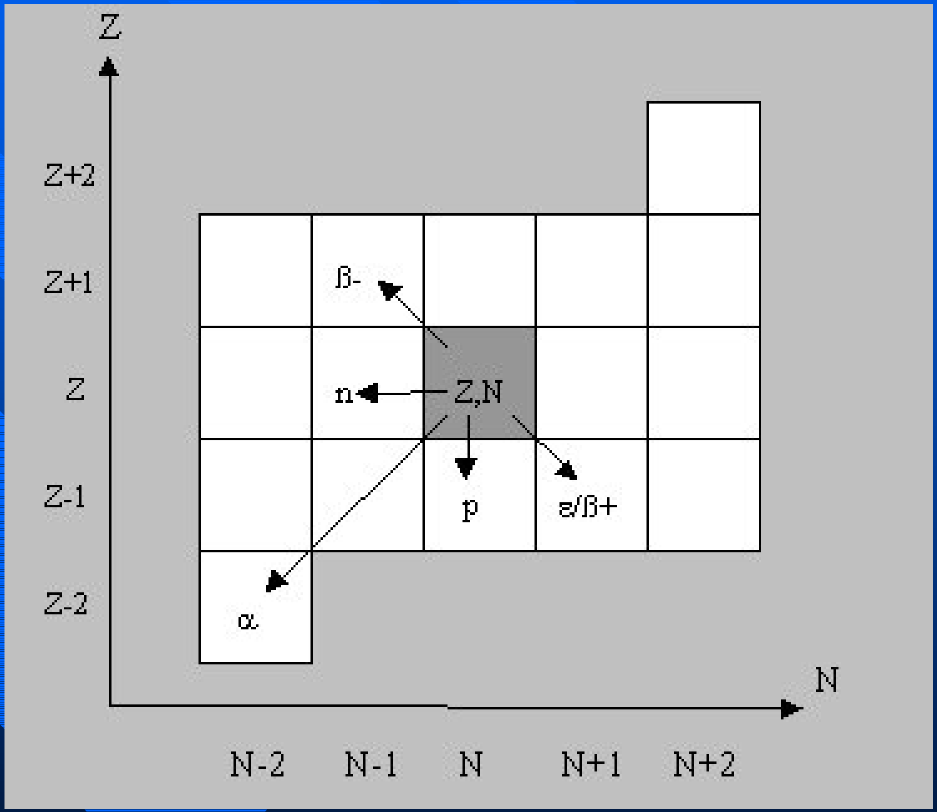
Types of Nuclear Decay

Excess p & n ⇒ alpha

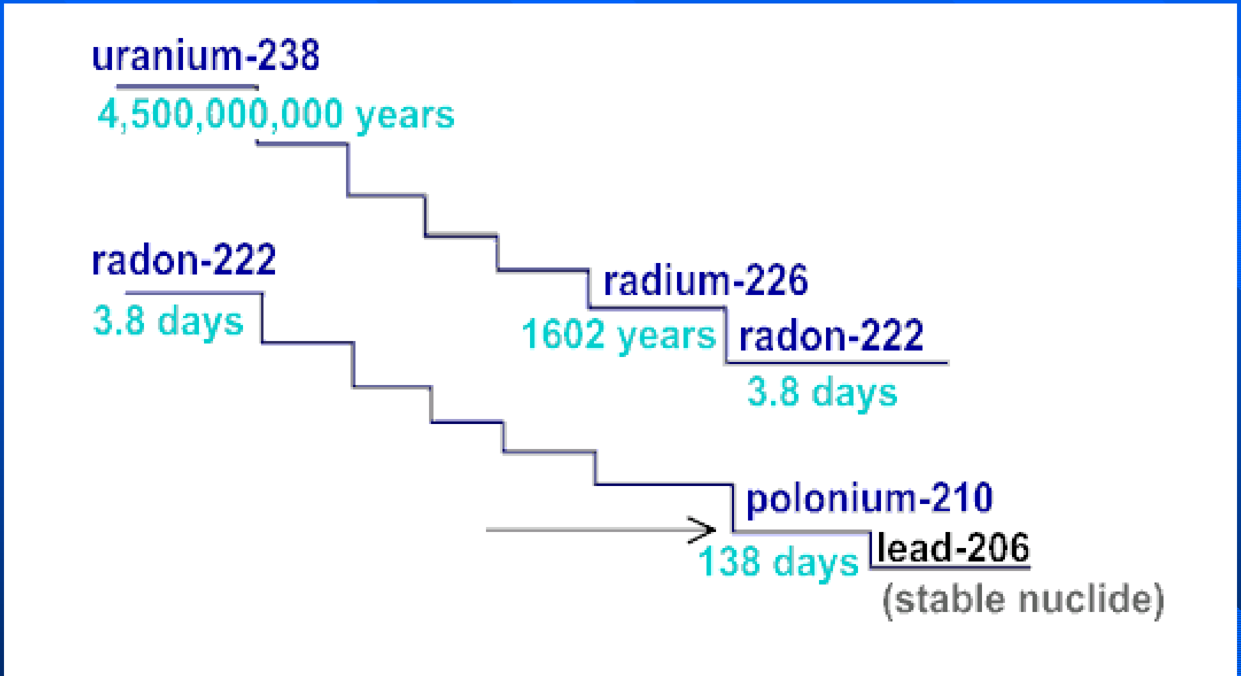
Excess p ⇒ positron (β^+)

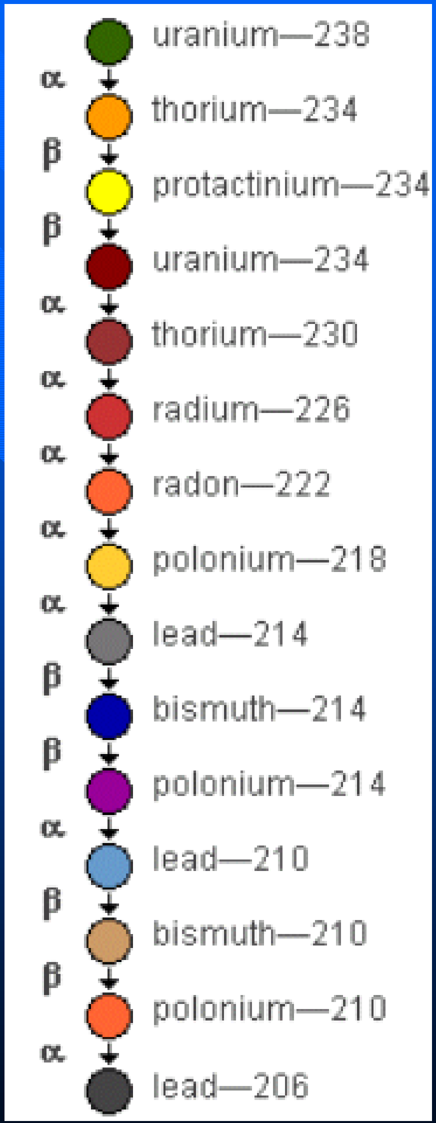
Excess n ⇒ negatron (β^-)

Excess nuclear E ⇒ gamma



U-238 decay chain

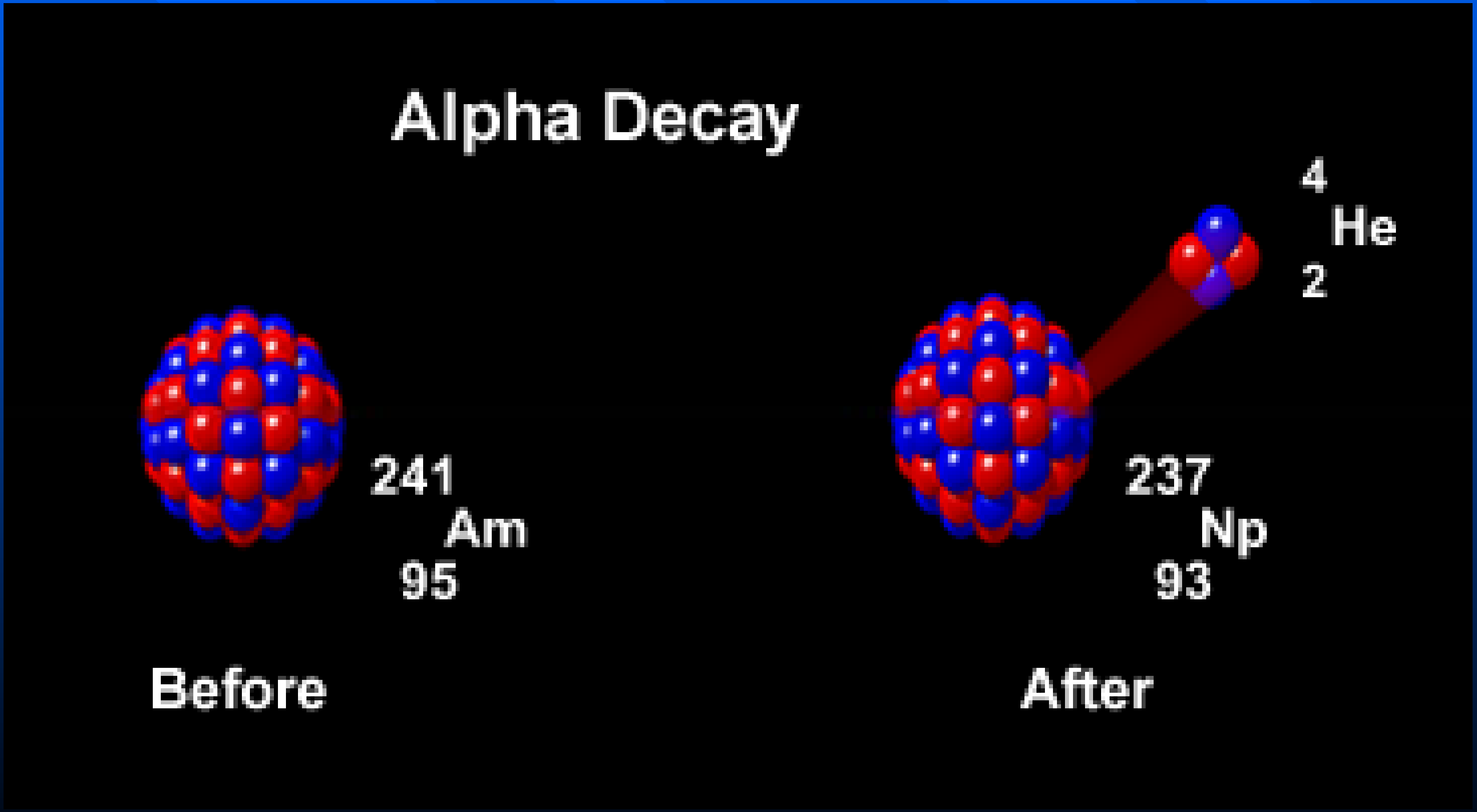




U-238 decays through a series of steps to become a stable form of lead.

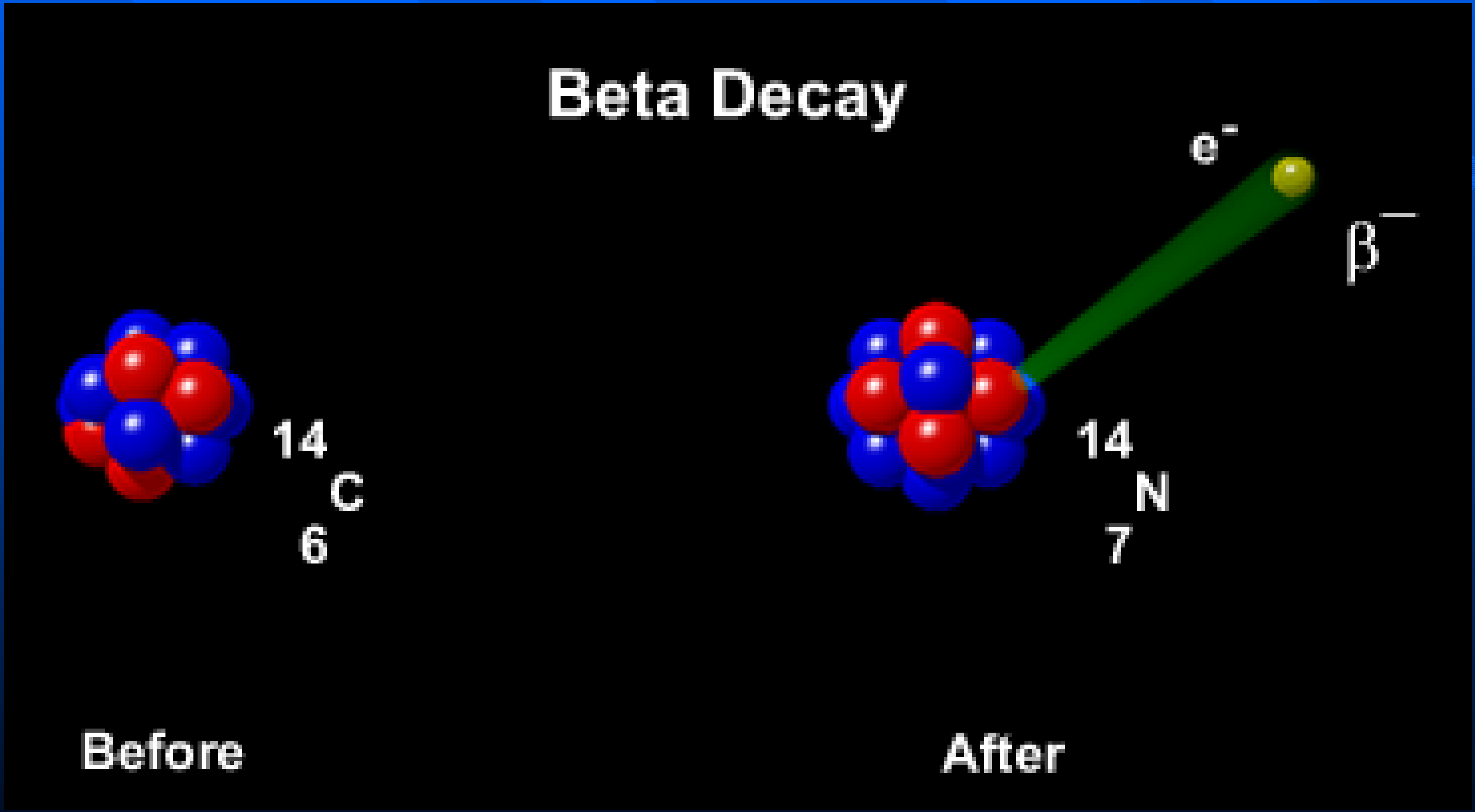
ALPHA DECAY

Very large nuclei may need to emit more than one particle in order to become stable. These atoms will emit an alpha particle.



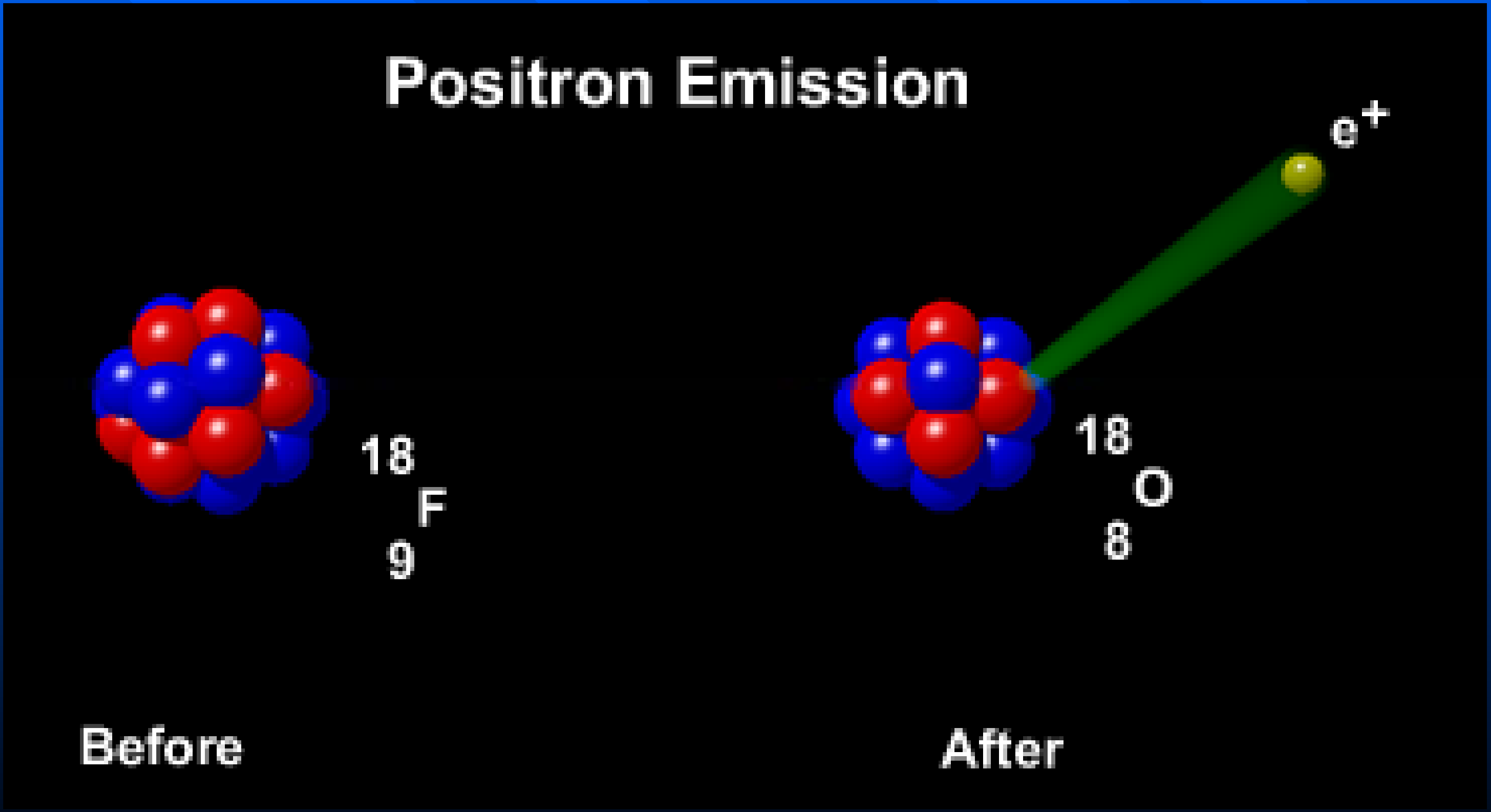
BETA DECAY

Too many neutrons results in decay by the emission of an electron



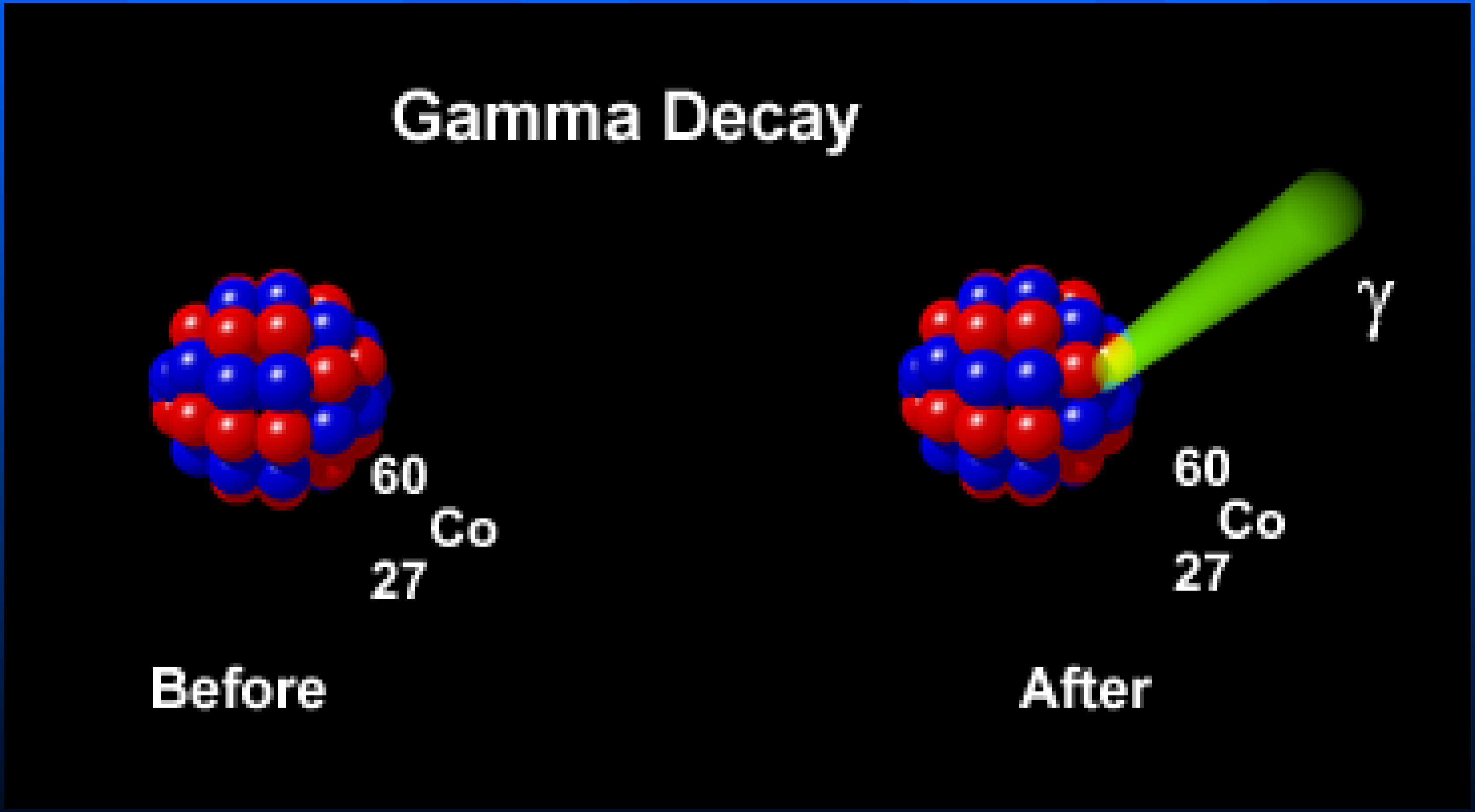
BETA DECAY

Too little neutrons results in decay by the emission of a positron



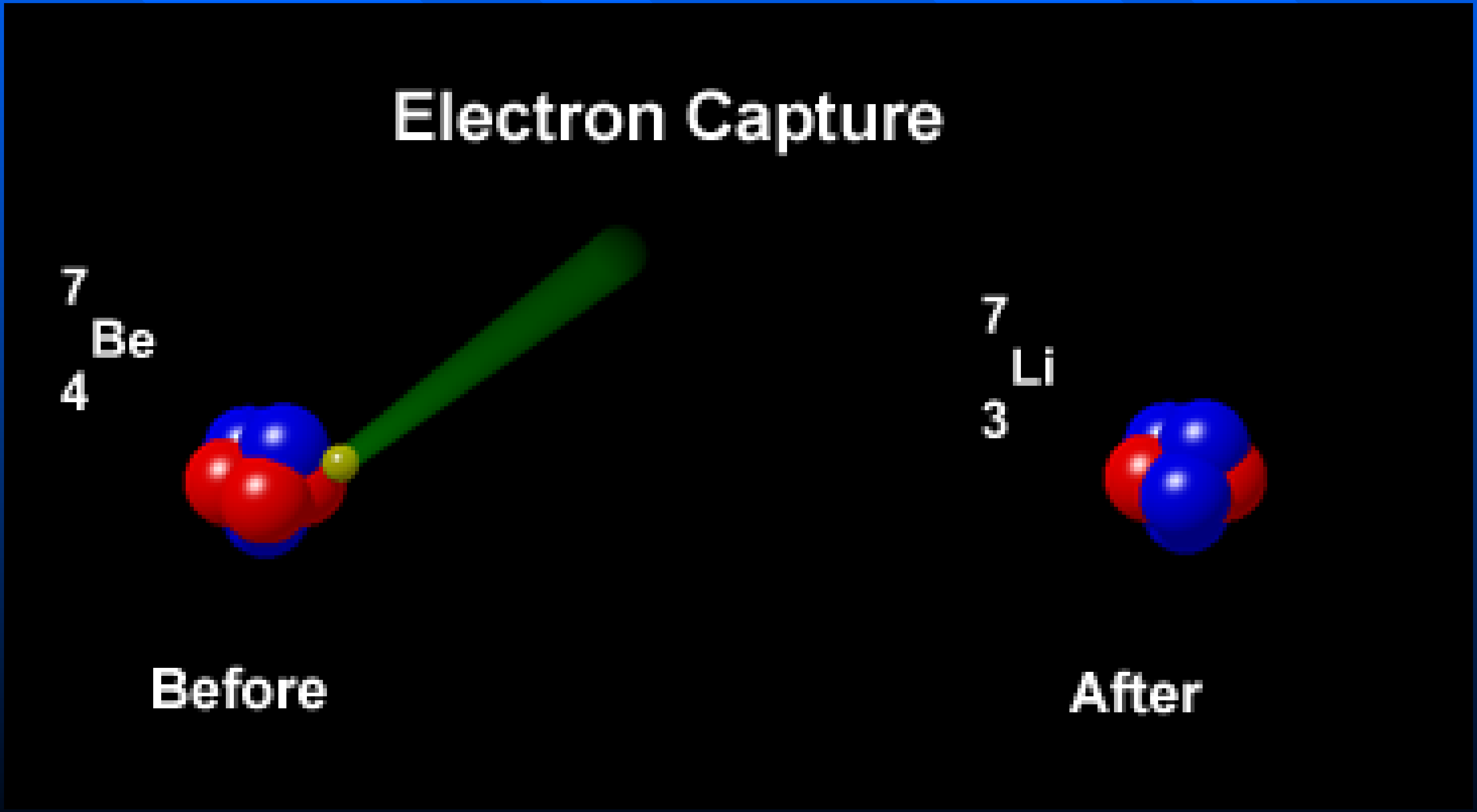
GAMMA DECAY

The nucleus may have excess energy that will be released in the form of a **gamma ray** (γ)



ELECTRON CAPTURE

An electron is captured by the nucleus changing one of the protons into a neutron. This causes a decrease in atomic number (Z) but no change to the atomic mass (A).



ALPHA EMISSION

- origin: DISINTEGRATING NUCLEUS
- form of radiation: PARTICLE
- energy range: 4-8 MeV
- range of travel: 2-8 cm in air
- other characteristics: LARGE MASS, DOUBLE CHARGE, HIGH SPECIFIC ACTIVITY

BETA EMISSION

- origin: DISINTEGRATING NUCLEUS
- form of radiation: NEGATRON (electron)
  POSITRON (similar to an electron but positive charge)
- energy range: 0.02 - 4.8 MeV
- range of travel: 0 - 10 m in air
- other characteristics: DIFFERS FROM AN ELECTON IN ORIGIN AND ENERGY ,TRAVELS ALMOST THE SPEED OF LIGHT, MASS (9.1x 10^{-31} kg)

GAMMA EMISSION

- origin: NUCLEUS
- form of radiation: ELECTROMAGNETIC RADIATION (emr - photon)
- energy range: 10 keV - 3 MeV
- range of travel: > 100 m in air
- other characteristics: Zero mass, no charge

X- RAY EMISSION

- origin: ORBITAL ELECTRON
- form of radiation: ELECTROMAGNETIC RADIATION (emr - photon)
- energy range: 10eV - 1 MeV
- range of travel: 100 m in air
- other characteristics: Zero mass, no charge

Neutron and Other Radiations

- Neutron radiation are produced in nuclear reactors (nuclear fission)
- Neutron can be produced by mixing alpha emitting radionuclide with beryllium

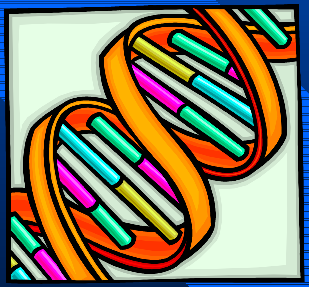
$$^{9}Be + {}^{4}He = {}^{12}C + n$$

- Other atomic particles (leptons, baryons, mesons) can be produced using particle accelerators (high energy physics)

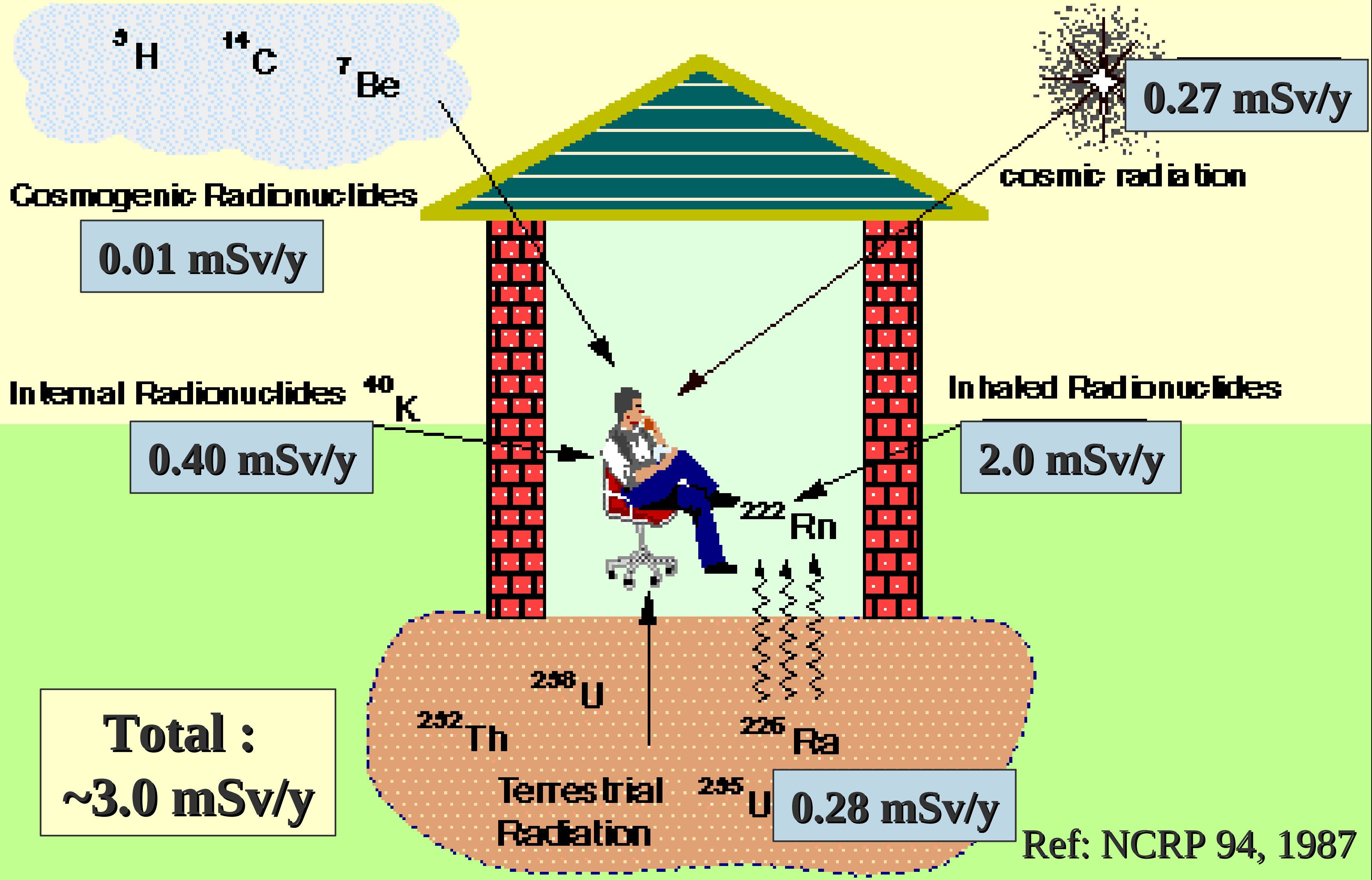
Isotope Emissions

Isotopes	Half-life	Type(s)of emission
P^{32}	14.3 d	β (1.709 MeV)
P^{33}	25.4 d	β (249 keV)
Cr^{51}	27.7 d	γ (0.323 MeV, 5 keV)
Fe^{59}	44.5 d	β (1.3 MeV, 1.6 MeV)
I^{125}	59.6 d	γ(35keV)+ X(27 - 32keV)
S^{35}	87.4 d	β (0.167 MeV)
Ca^{45}	163 d	β (0.257 MeV)
H^{3}	12.4 *yr*	β (18.6 keV)
C^{14}	5760 *yr*	β (0.156 MeV)

MODULE 3
Radiation and Risks



Estimated Total Effective Dose Equivalent Rate to Public from Background Radiation (US and Canada)

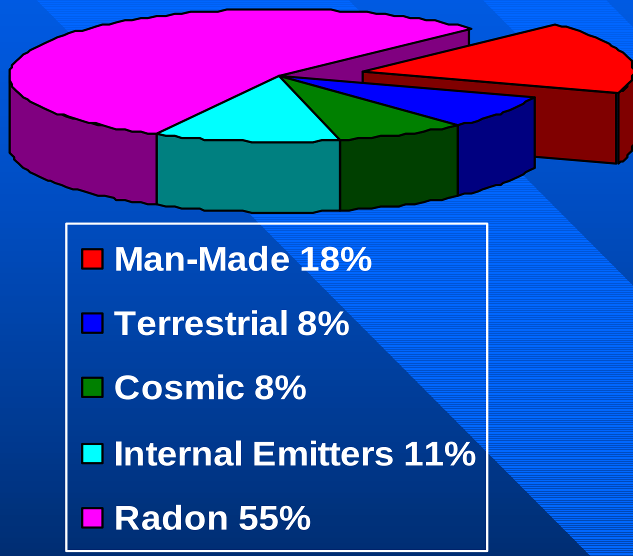


Total : ~3.0 mSv/y

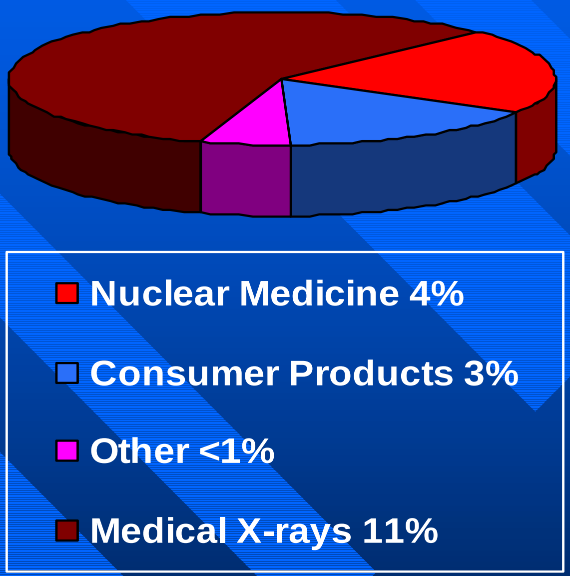
Ref: NCRP 94, 1987

Sources of Radiation

Natural Sources



Man Made Sources

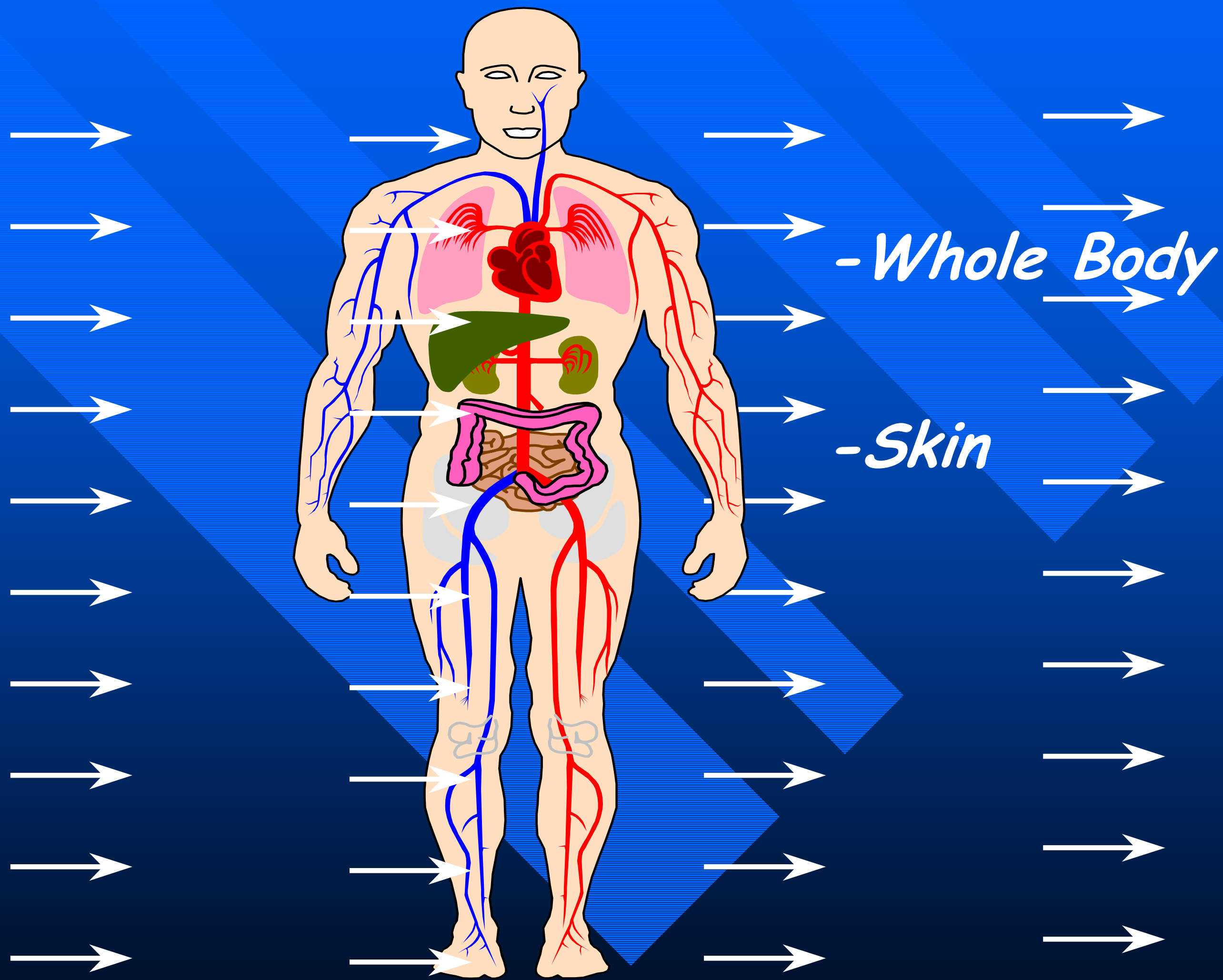


The average Canadian receives an annual dose of 3.6 mSv of exposure annually

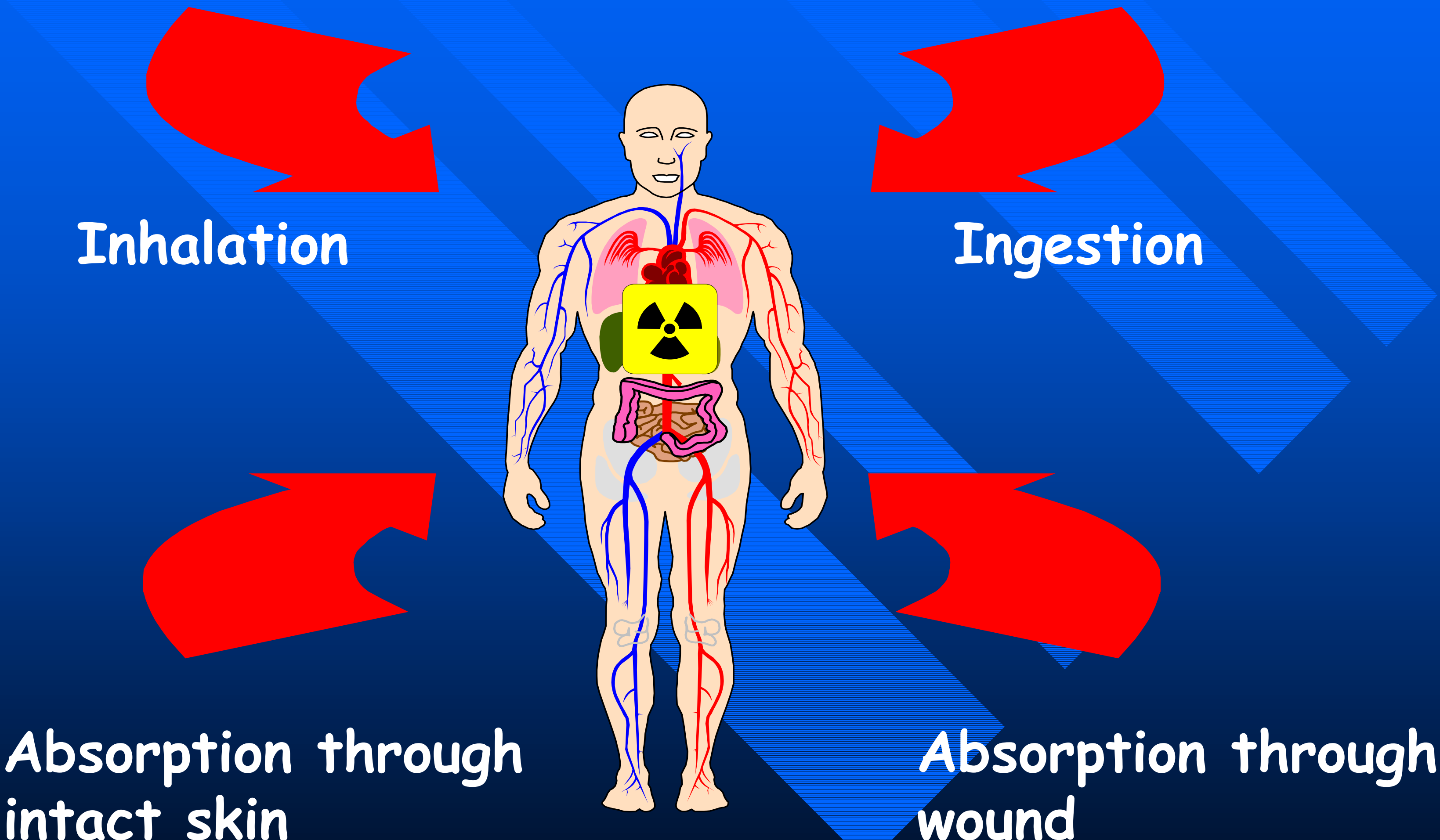
Other:

Occupational	0.3%
Fallout	0.3%
Nuclear Power	0.1%
Miscellaneous	0.1%

Routes of Exposure
External Radiation Field



Routes of Exposure
Internal Contamination



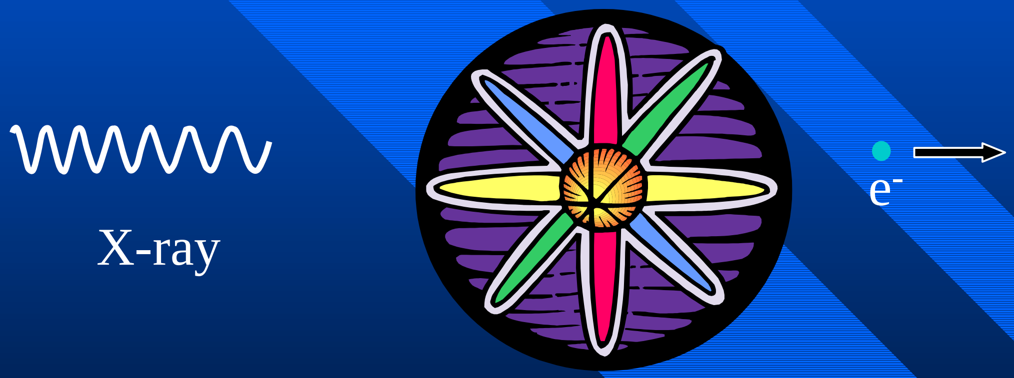
X-rays and Matter

3 main interactions for X-rays

- Photoeffect
- Compton Scattering
- Pair Production

Photoeffect

- All the energy of an X-ray is given to an orbital electron



- Result: High energy electron

Compton Scatter

- X-ray gives part of its energy to orbital electron

- Result: High energy electron

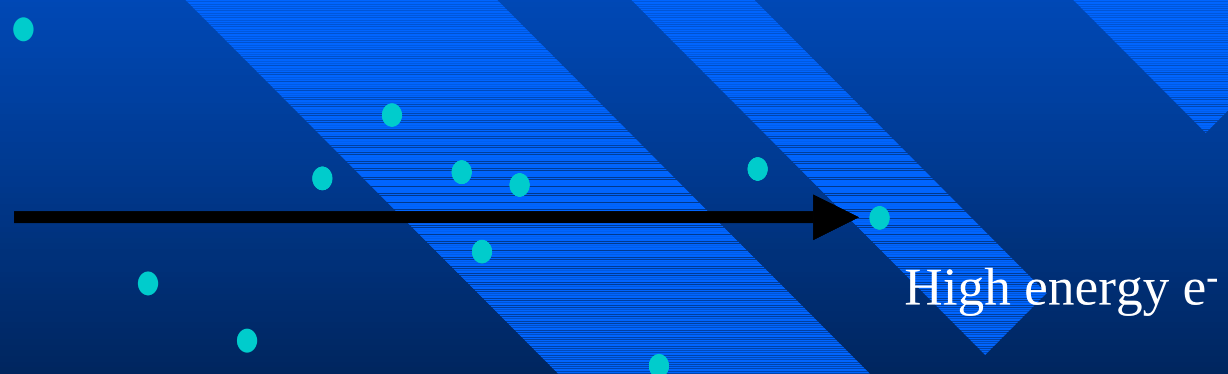
Pair Production

- X-ray has enough energy to convert into electron-positron pair

- Result: High energy electron & positron

Charged Particles in Matter

- High energy electrons transfer their energy to orbital electrons as they move through media



- Creation of many ions

Net Results of Interactions

- Large number of ionized atoms from electron interactions

X-ray

↓

High energy electrons

↓

Low energy electrons + ions

The Absorbed Dose $D_{T,R}$

- The **Absorbed dose** ($D_{T,R}$ in Gy) is the quotient obtained by dividing the energy absorbed through exposure to radiation by the mass of the body that absorbs that radiation

- Units : gray (Gy) = 1 Joule / Kg

The Equivalent Dose H_T

- The sum of the products, in Sievert (Sv), obtained by multiplying the absorbed dose ($D_{T,R}$ in Gy) by the radiation weighting factors (w_R) for a type of radiation

$$H_T = \Sigma w_R D_{T,R}$$

Type of radiation	w_R
Photons	1
Electrons	1
Neutrons	5-20
Protons	5
Alpha	20

The Effective Dose E

- The sum of the products, in Sievert (Sv), obtained by multiplying the equivalent dose (in Sv) received by an organ by the tissue weighting factors W_T for that organ

$$E = \Sigma W_T H_T$$

- The tissue weighting factors W_T is related to the risk of carcinogenesis in the tissue T

The Committed Dose H_{50}

- For radioactive material taken into the body, the committed dose is the equivalent dose rate $\dot{H}(t)$ to an organ integrated over a period of 50 years following intake

$$H_{50} = \int \dot{H}(t)\, dt$$

Effective Dose Limits

Person	Period	Effective Dose (mSv)
Nuclear energy worker, including a pregnant nuclear energy worker	(*a*) One-year dosimetry period	50
	(*b*) Five-year dosimetry period	100
Pregnant nuclear energy worker	Balance of the pregnancy	4
A person who is not a nuclear energy worker	One calendar year	1

Equivalent Dose Limits

Organ or Tissue	Person	Period	Equivalent Dose (mSv)
Lens of an eye	(*a*) Nuclear energy worker	One-year dosimetry period	150
	(*b*) Any other person	One calendar year	15
Skin	(a) Nuclear energy worker	One-year dosimetry period	500
	(*b*) Any other person	One calendar year	50
Hands and feet	(*a*) Nuclear energy worker	One-year dosimetry period	500
	(*b*) Any other person	One calendar year	50

Biological Effects of Radiation

- Injury to living tissue results from the transfer of energy to atoms and molecules (ionization)

  - Produce free radicals.
  - Break chemical bonds.
  - Damage molecules that regulate vital cell processes (e.g. DNA, RNA, proteins).

- The cell can repair certain levels of cell damage.
  - At low doses cellular damage is rapidly repaired.
  - At higher levels, cell death results and tissues may fail to function.

Biological Effects of Radiation

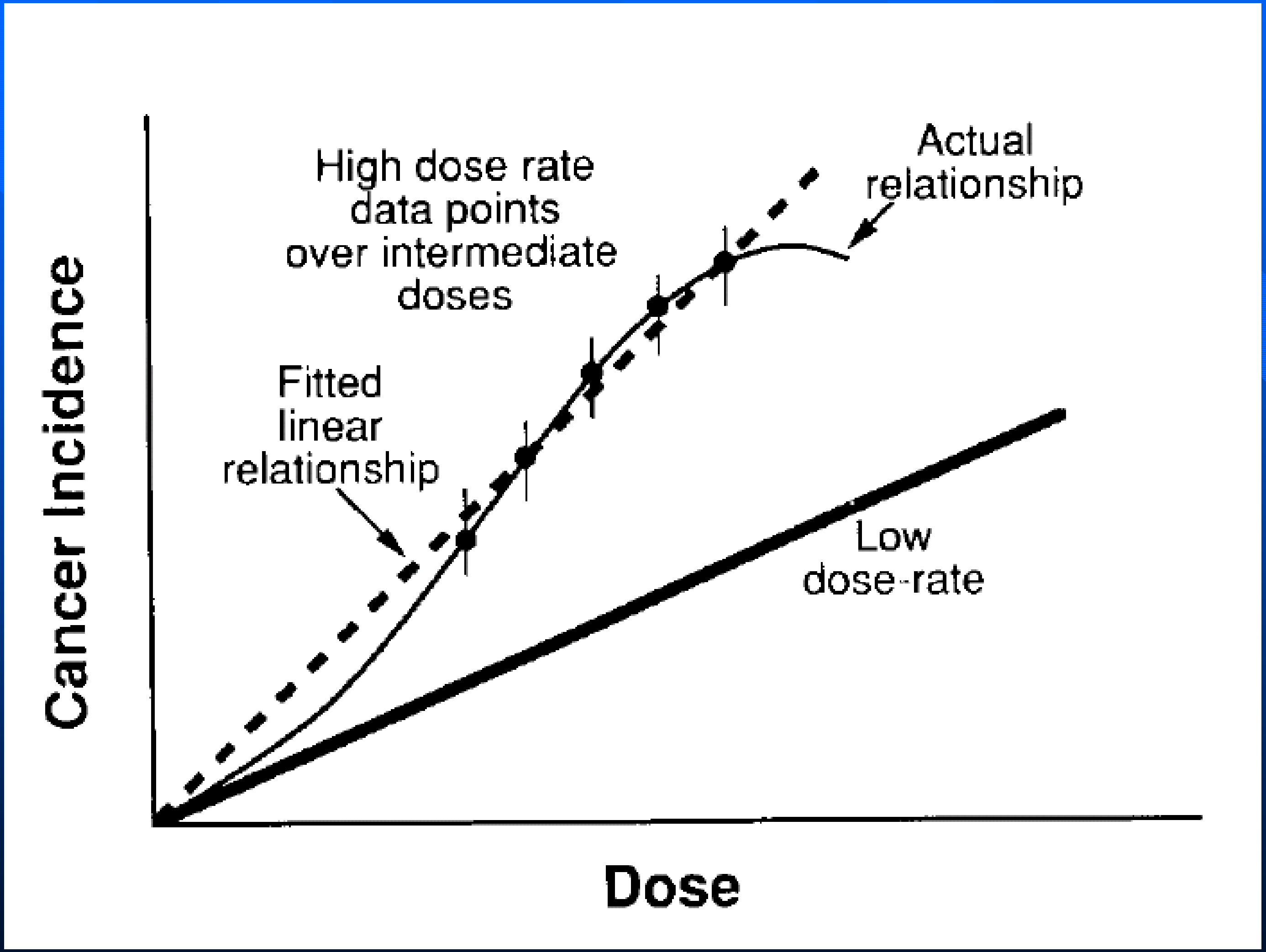
- Deterministic Effects
  - Loss of function of tissues in organs due to cell loss (ex. Radiation induced cataracts)
  - Result from high dose exposure for which there is a threshold
- Stochastic Effects
  - Cell changes (mutation) may occur due to radiation
  - Severity of condition is not increased with dose, but occurrence increases
  - We assume there is no threshold dose

    (eg. Cancer, genetic mutation)

Human Data for Radiation Effects

- Japanese survivors of A-bomb
- Early radiotherapy studies
  - » Britain 1935-44 ankylosing spondytlitis treatments with radiation to spine
  - » Radiology prior to 1922
  - » 1950's treatment of ringworm in the scalp of children
- High doses in early diagnostic work
  - » Tuberculosis studies using fluoroscopy, Canada & US

Linear quadratic Model



ICRP and NCRP preferred model

Linear quadratic Model

Table 19-3.
ICRP Summary of Risks of Cancer Lethality by Radiation

	HIGH DOSE HIGH DOSE RATE	LOW DOSE LOW DOSE RATE
Working population	8×10^{-2} per Sv	4×10^{-2} per Sv
Whole population	10×10^{-2} per Sv	5×10^{-2} per Sv

(International Commission on Radiological Protection: Recommendations. Annals of the ICRP Publication 60. Oxford, Pergamon Press, 1990)

Putting Risk into Perspective

Health Risk	Estimated Life Expectancy Lost
Smoking 20 cigarettes a day	6 years
Overweight by 15%	2 years
Alcohol (US Average)	1 year
All accidents	207 days
All natural hazards	7 days
Occupational dose of 3 mSv/year	15 days

Ref. : B. L. Cohen and L. S. Lee, "Catalogue of Risks Extended and Updates," Health Physics, Vol. 61, September 1991.

Acute Exposure

Effects of Acute Exposure to Specific Organs

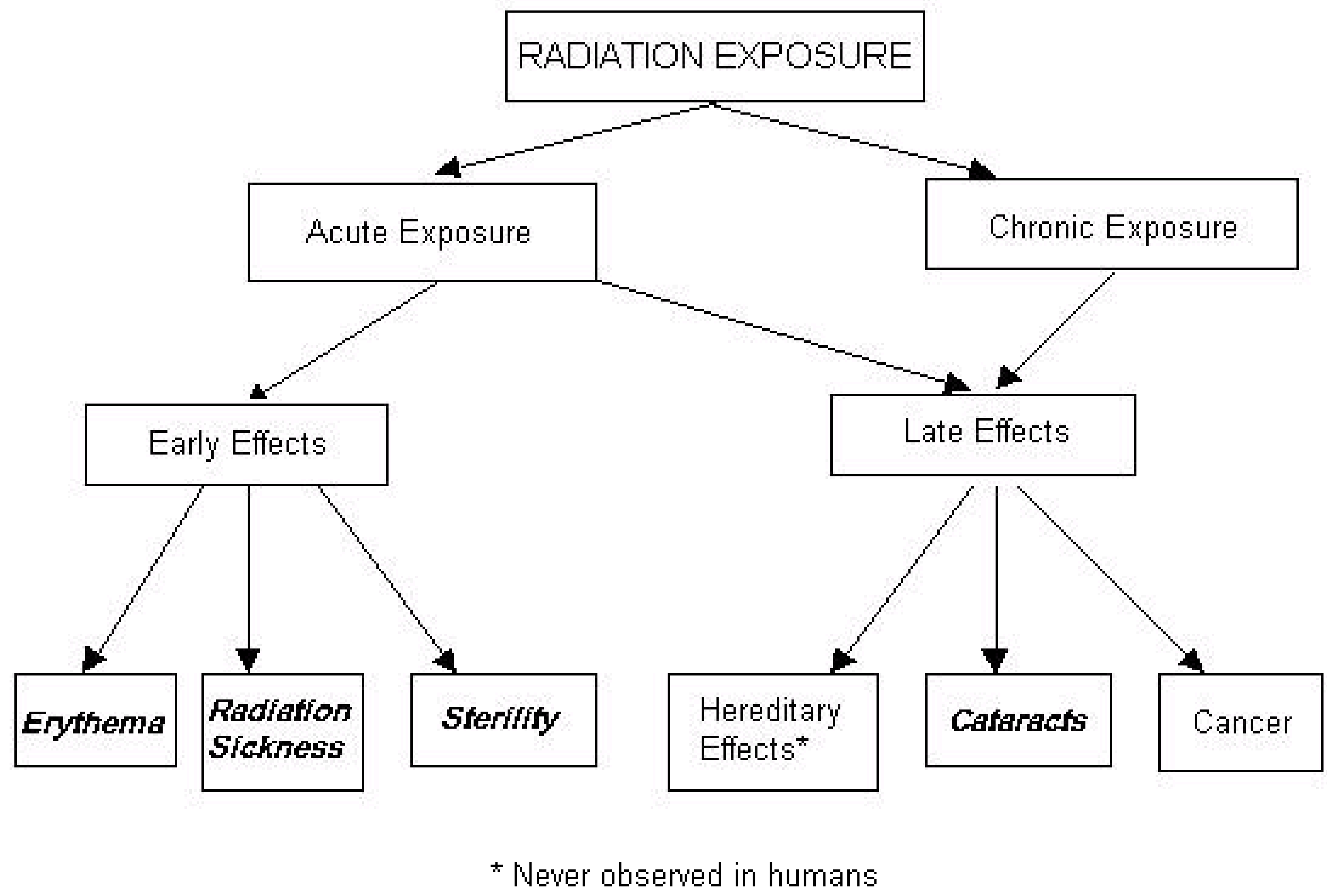
Dose (mSv)	Organ	Effect
3 500	Testes	Permanent sterility
3 500	Eye	Later cataract formation
3 000	Ovaries	Sterility
2 500+	Skin	Skin reddening (erythema) and possible permanent hair loss
500	Bone marrow	Reduced blood cell formation
150+	Testes	Temporary sterility
60	Foetus	Probable minimum dose causing effect (possible malformation)

Acute Exposure

Effects of Acute Whole Body Exposure to Radiation

Dose (mSv)	Effect
50 000+	Severe damage to central nervous system – rapidly lethal.
8 000 - 50 000	Destruction of lining of intestine and white blood cells – death within two weeks.
4 000	Fatal for half those irradiated within 30 days without medical treatment.
2 000 - 8 000	Damage to white blood cells and gut lining. Death may result from secondary infection but can be avoided in many cases with special medical treatment.
1 000 - 2 000	Possible radiation sickness – nausea, vomiting, diarrhoea – not lethal.

Summary of Radiation Effects



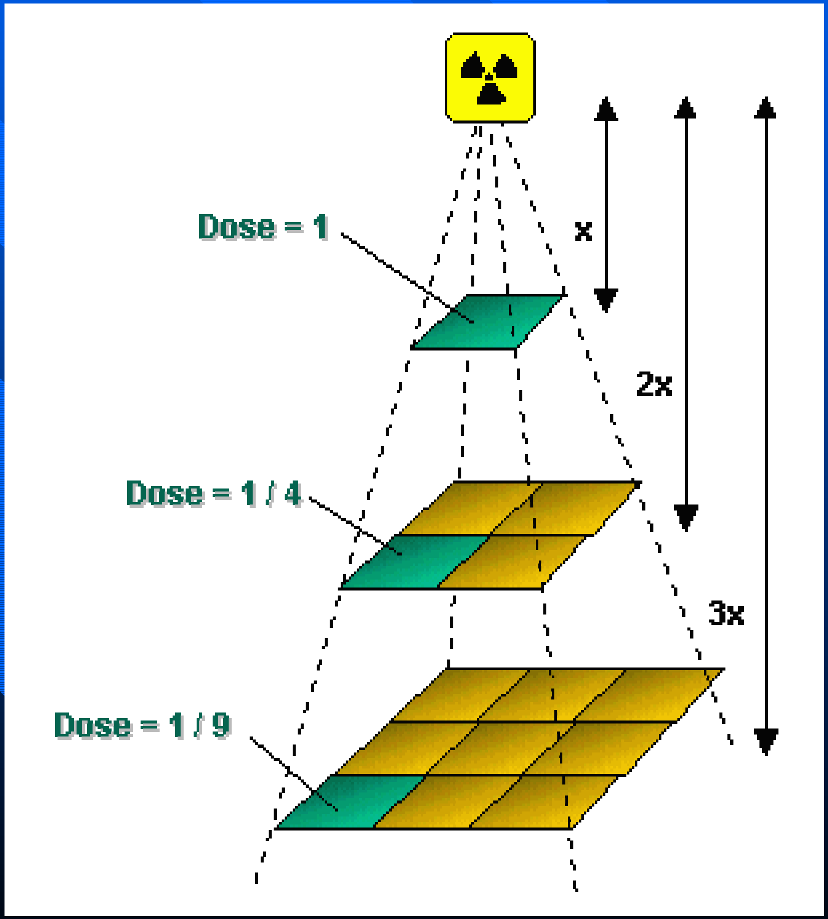
ALARA Principle

- Doses are required to be kept As Low As Reasonably Achievable
- Further ALARA analysis not required if
  - Individual occupational doses unlikely to exceed 1 mSv/year
  - Dose to public unlikely to exceed 50 µSv/year
  - Annual collective dose unlikely to exceed 1 person-Sv
- Expenditure in excess of $100,000 to reduce collective dose by 1 person-Sv not justified

What to do to protect yourself….

Basic Radiation Safety Principles for External Radiation

- Time ↓
- Distance ↑
- Shielding ↑



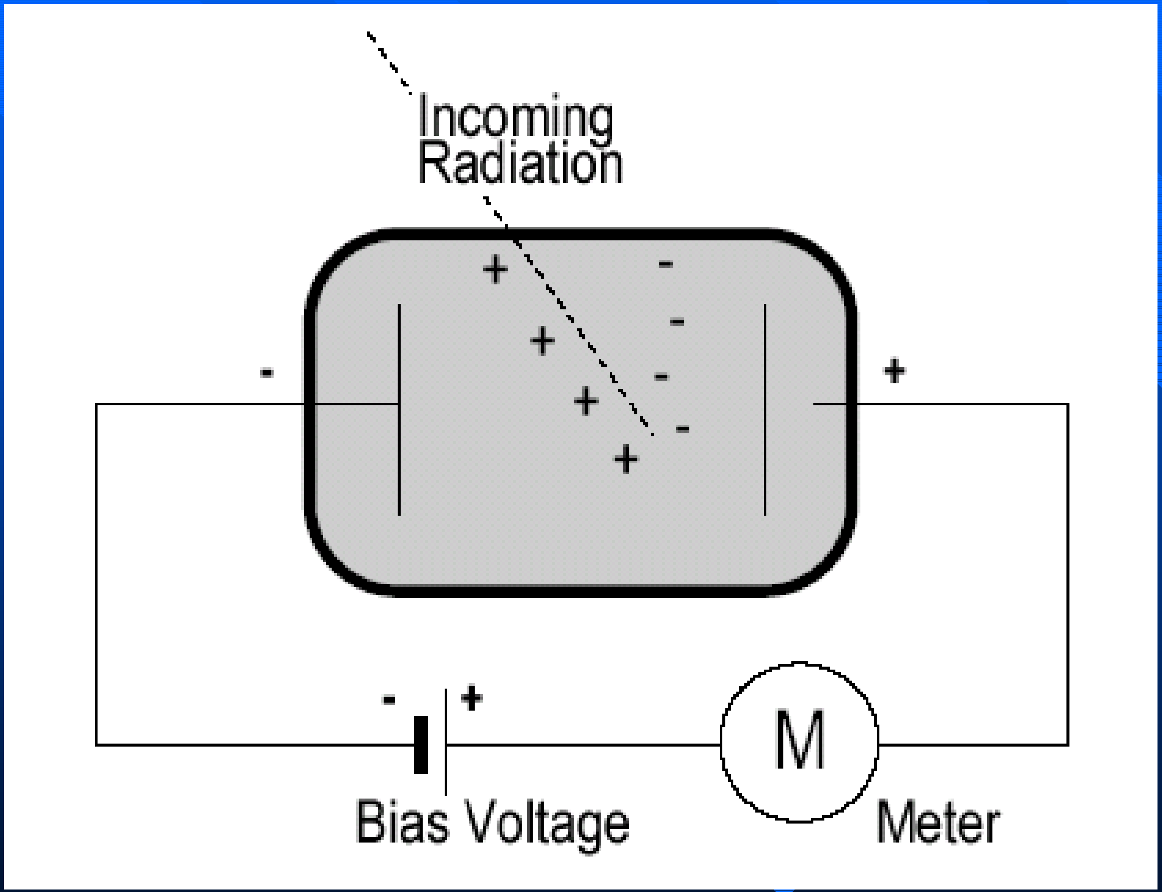
MODULE 4

Detection Instruments and Survey techniques

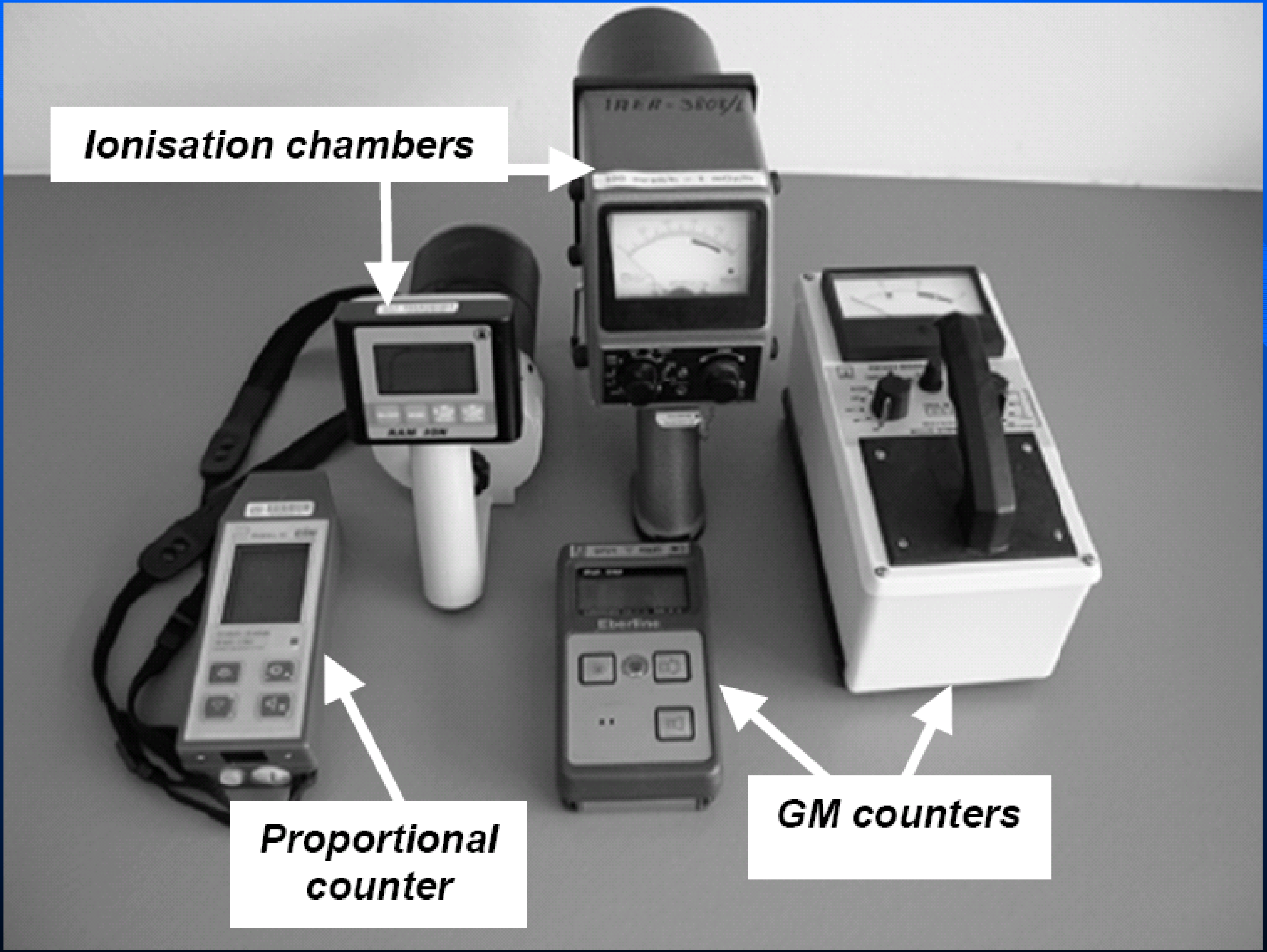
Types of Radiation Detectors

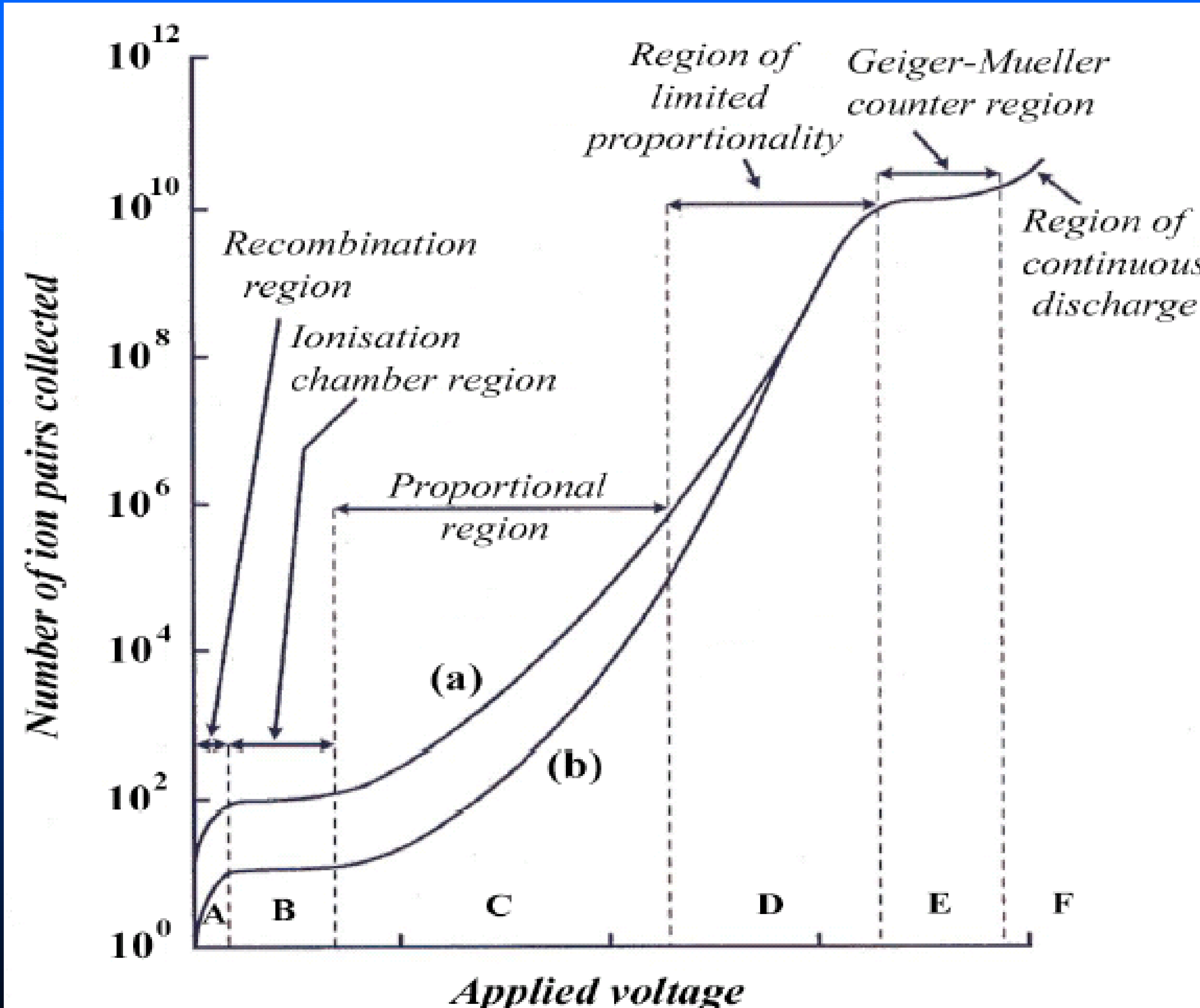
- Gas-filled detectors
  - Ionization chamber
  - Proportional counter
  - Geiger-Mueller detector
- Semiconductor detectors
- Scintillation detectors
  - Na(Tl)
  - Liquid scintillation detectors
- Personal Dose Monitors
  - TLD, Film badges, EPD

Gas-Filled Detectors



Gas-Filled Detectors




Region of limited proportionality
Geiger-Mueller counter region
Region of continuous discharge
Recombination region
Ionisation chamber region
Proportional region
(a)
(b)
A
B
C
D
E
F
10^12
10^10
10^8
10^6
10^4
10^2
10^0
Number of ion pairs collected
Applied voltage

Gas-filled Detectors

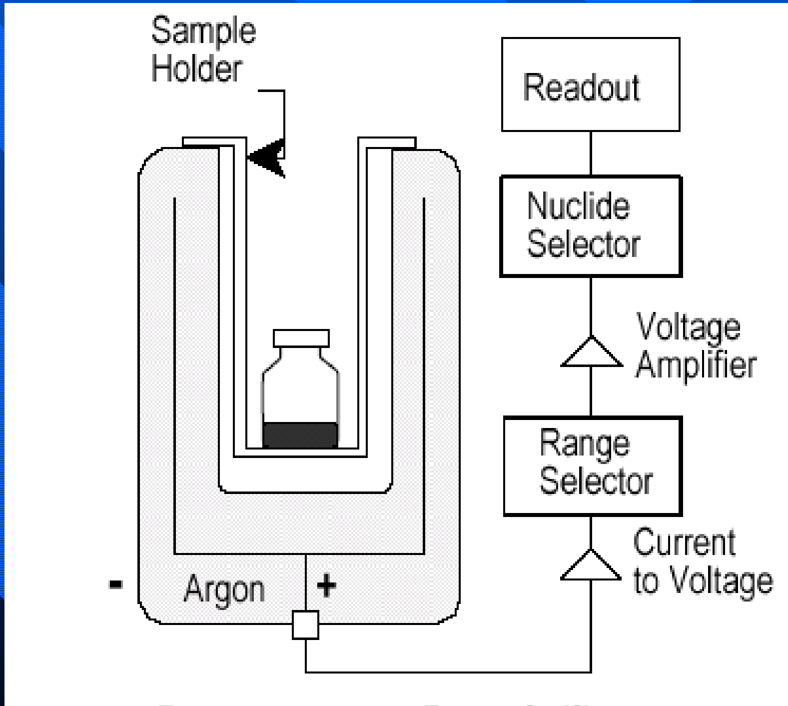
- Ionization Chamber (B)
  - # primary ions collected ~ E deposited
  - Use build-up cap at high energy
- Proportional counter (C)
  - # ions collected ~ E deposited
  - Charge amplification of 10^3 –10^4
  - Suitable for low intensity rad. field

Gas-filled Detectors

- Geiger Mueller detector (E)
  - Signal independent of E deposited
  - Large amplification of 10^9 –10^{10}
  - Used at VERY LOW radiation levels
  - Indicator of radiation

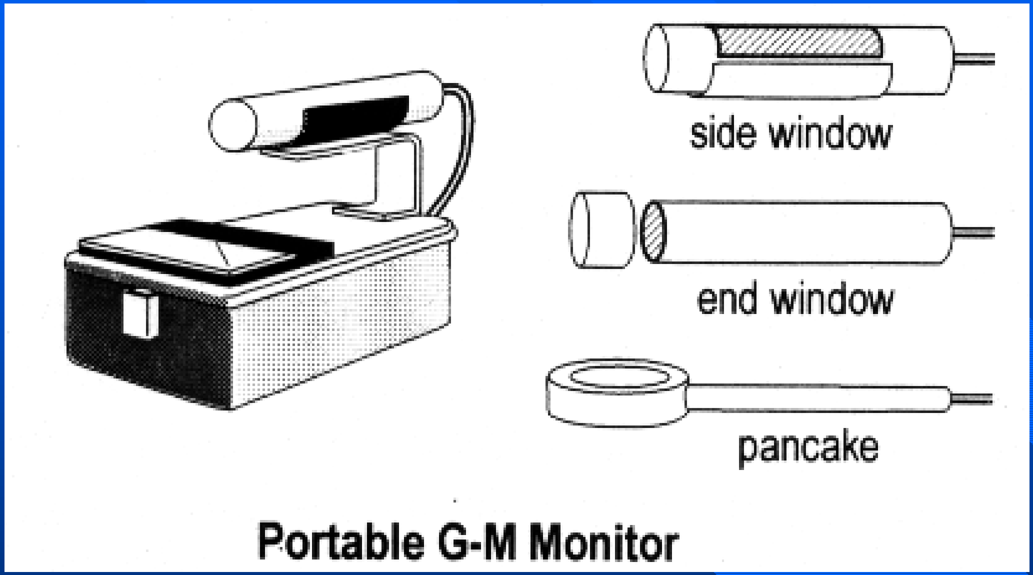
Dose Calibrator

- Ionization Chamber (well chamber)
- Calibration factors for each specific nuclides
- Measures "Activity" in MBq (or mCi) and not "Dose"



Re-entrant type Dose Calibrator

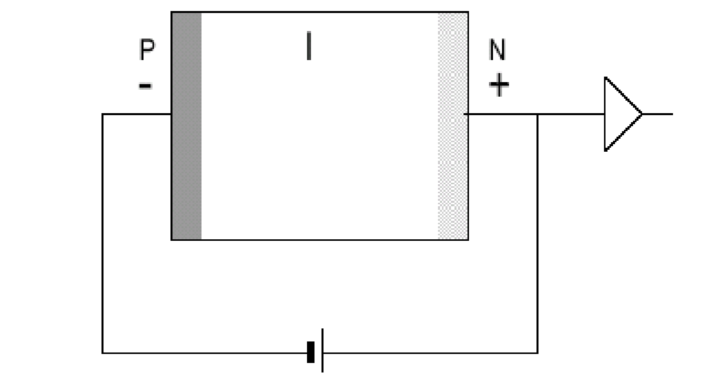
The Geiger Mueller Detector



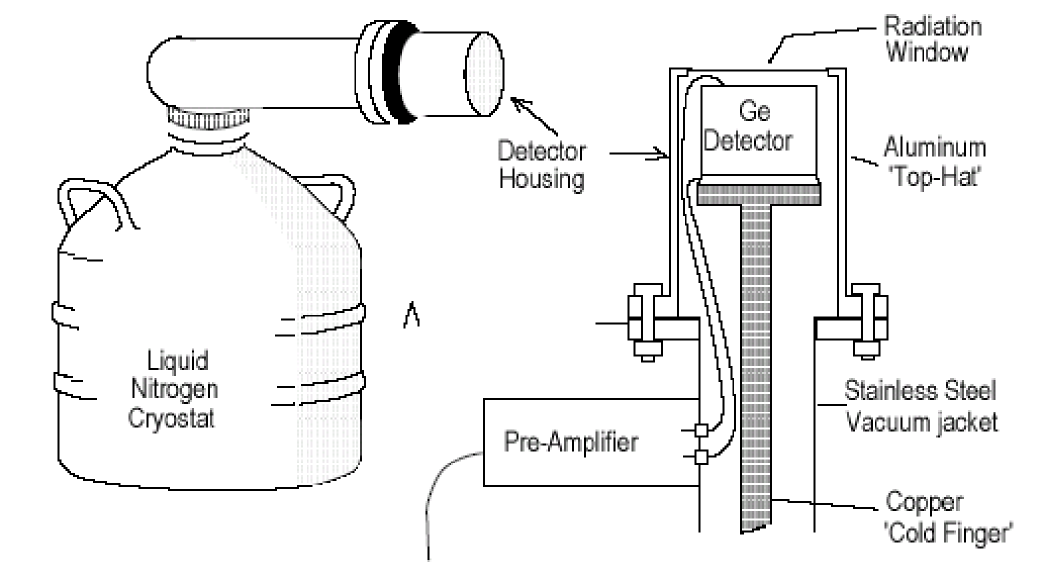
Pancake probe probe
(Thin mylar window)

- Tritium cannot be detected
- Efficiency to C-14 and S-35 is low (<5%)
- Efficiency to P-32 is high (~40%)
- Efficiency to gamma contamination is low (1-2%)

Semiconductor Detectors



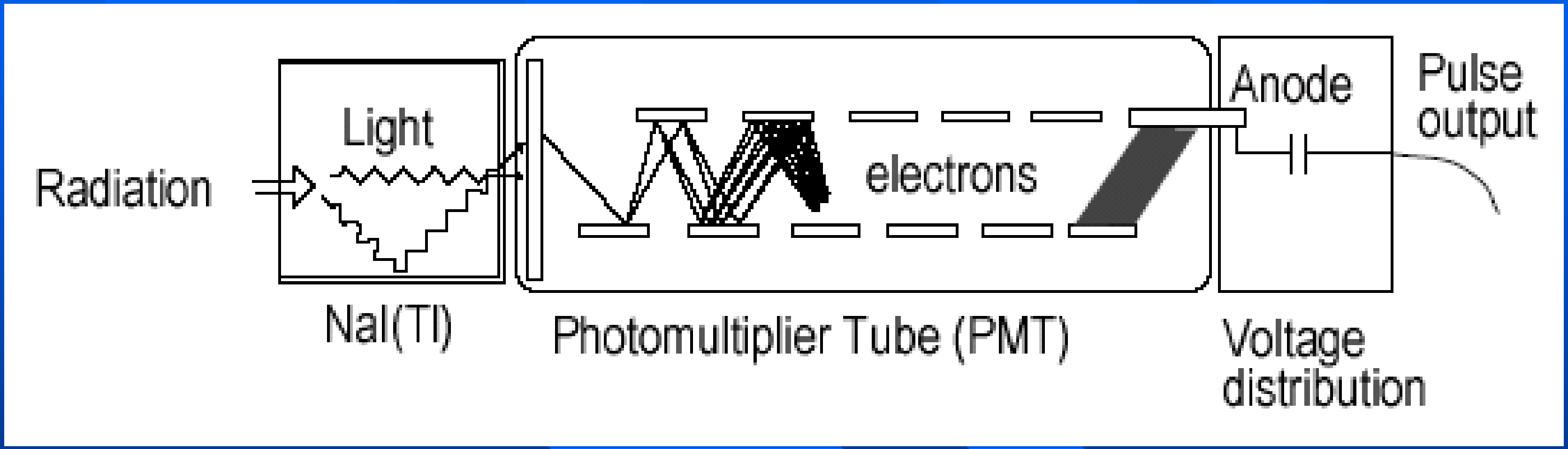
- May be viewed as "solid state" ion chambers (P-I-N junction)
- Sensitivity about ~10^4 higher than gas-filled detectors
- Helps in miniaturizing radiation monitoring instruments
- Ge(Li) used for gamma ray spectroscopy



Scintillation Detectors

- Based on scintillation (light emission)
- Phosphor materials
  - chemical substance that exhibits fluorescence when excited by radiation (UV, X-ray, electron)
  - amount of visible light is proportional to the amount of excitation energy.
  - Includes NaI(Tl), CsI(Tl)
- NaI(Tl) coupled to a photomultiplier tube (PMT) often used for survey meters

Scintillation Detectors

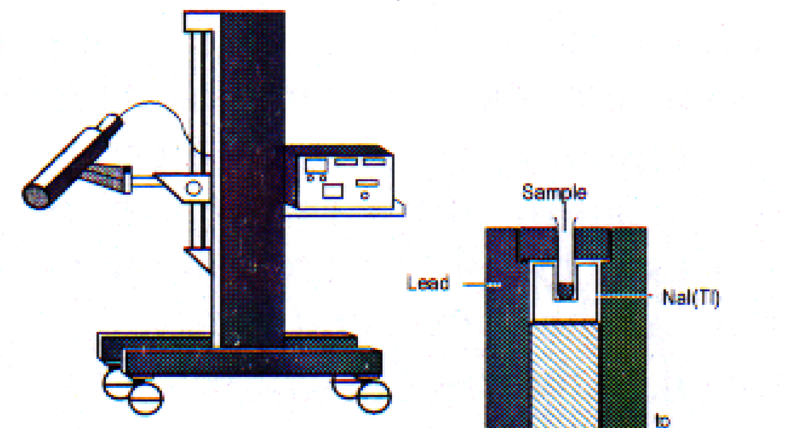


- Solid crystal inside the probe
- Electron excitation within the solid
- Light emission and multiplication
- Creates a current

Scintillation Detectors

Operation of NaI Detector

- Beta radiations cannot be detected.
- Efficiency is high (20%) for gamma contamination
- Need to use in low dose rate (<500 cpm).
- Will readily see Bremsstrahlung radiation from P-32



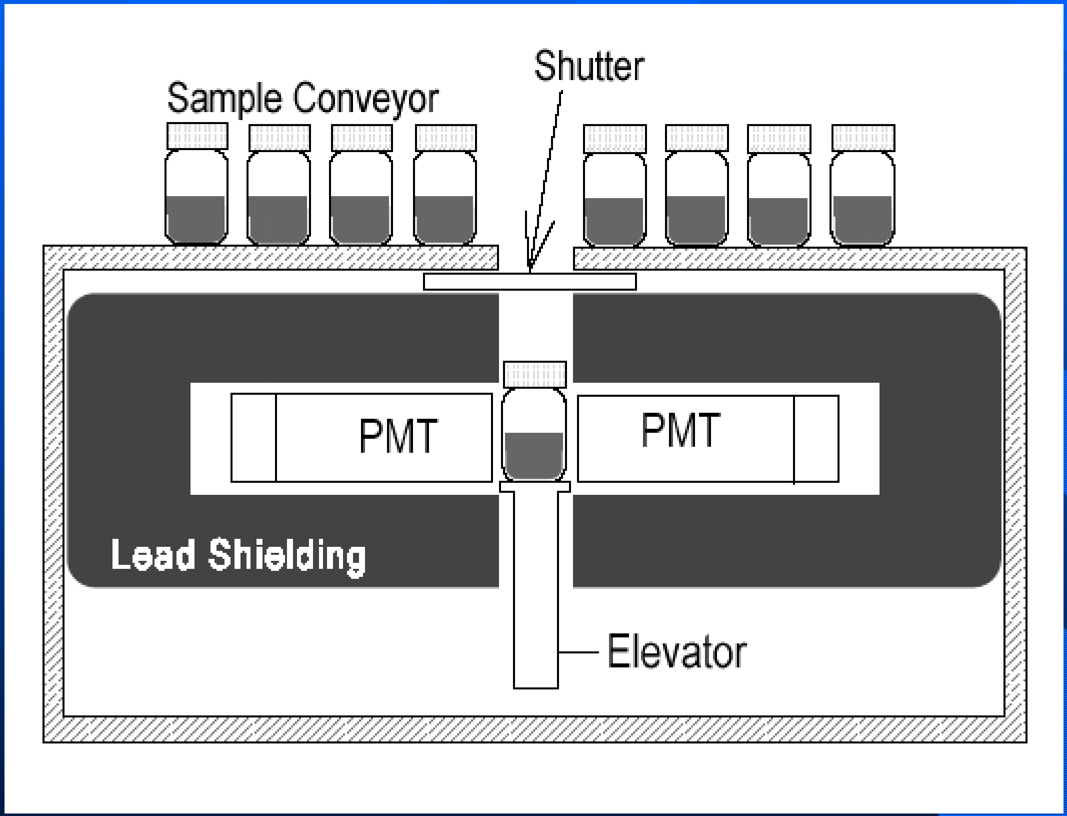
Thyroid Uptake Probe

Well Counter

Liquid Scintillation Detector

- Detects low energy beta particles (H-3, C-14)
- Use scintillation “cocktail” (organic solvent, fluorescent solute, dissolution agents) mixed with radioactive sample
- “Cocktail” absorbs radionuclide energy and emits light
- Light is collected by PMT
- All isotopes can be detected with high efficiencies (minimum 60%)

Liquid Scintillation Detector

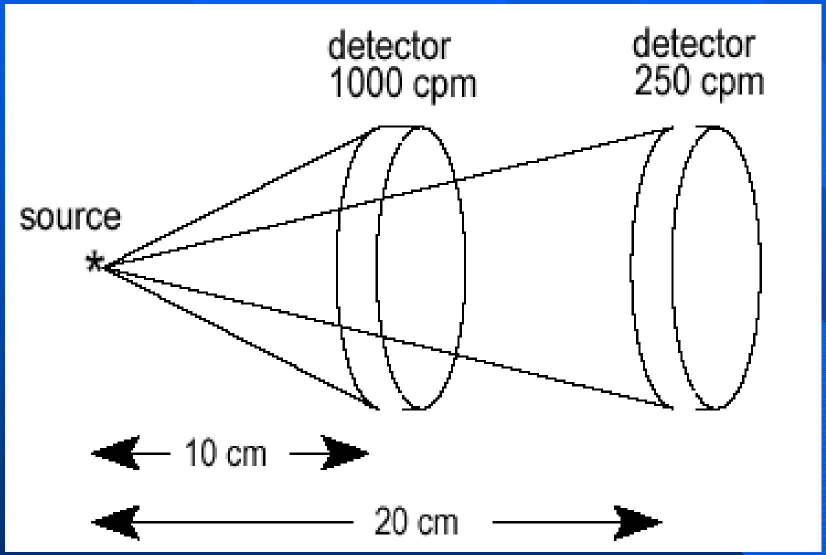


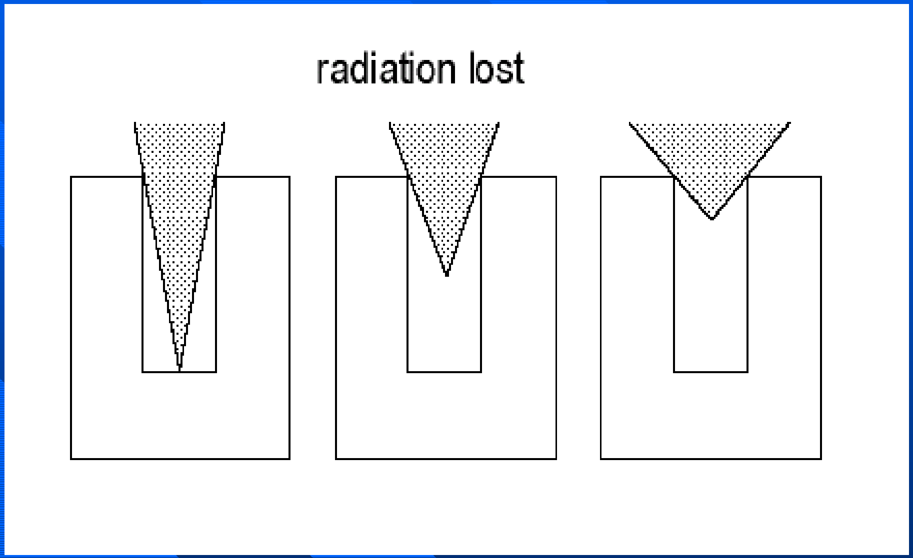
Automatic LS sample counter

Detected vs Emitted Radiation

- Factors affecting measurement :
  - Counting Geometry
    - » $1/r^2$ law
  - Detector efficiency
    - » Physical characteristics of detector
  - Deadtime
    - » Electronic limitation
  - Background radiation
    - » Natural bkg interfere with measurement
  - Counting statistics
    - » Radioactive decay is a random process

Detected vs Emitted Radiation





$1/r^2$ law : Doubling the distance decreases radiation detected by 4

Radiation losses vs source position in a well counter

Personal Dose Monitors

- Measures radiation doses received by individuals working with radiation
- Verify effectiveness of radiation control practices in the workplace
- Provide information in case of accidental exposure
- Most widely used are
  - TLD badges
  - Film badges
  - Direct reading monitors (EPD)

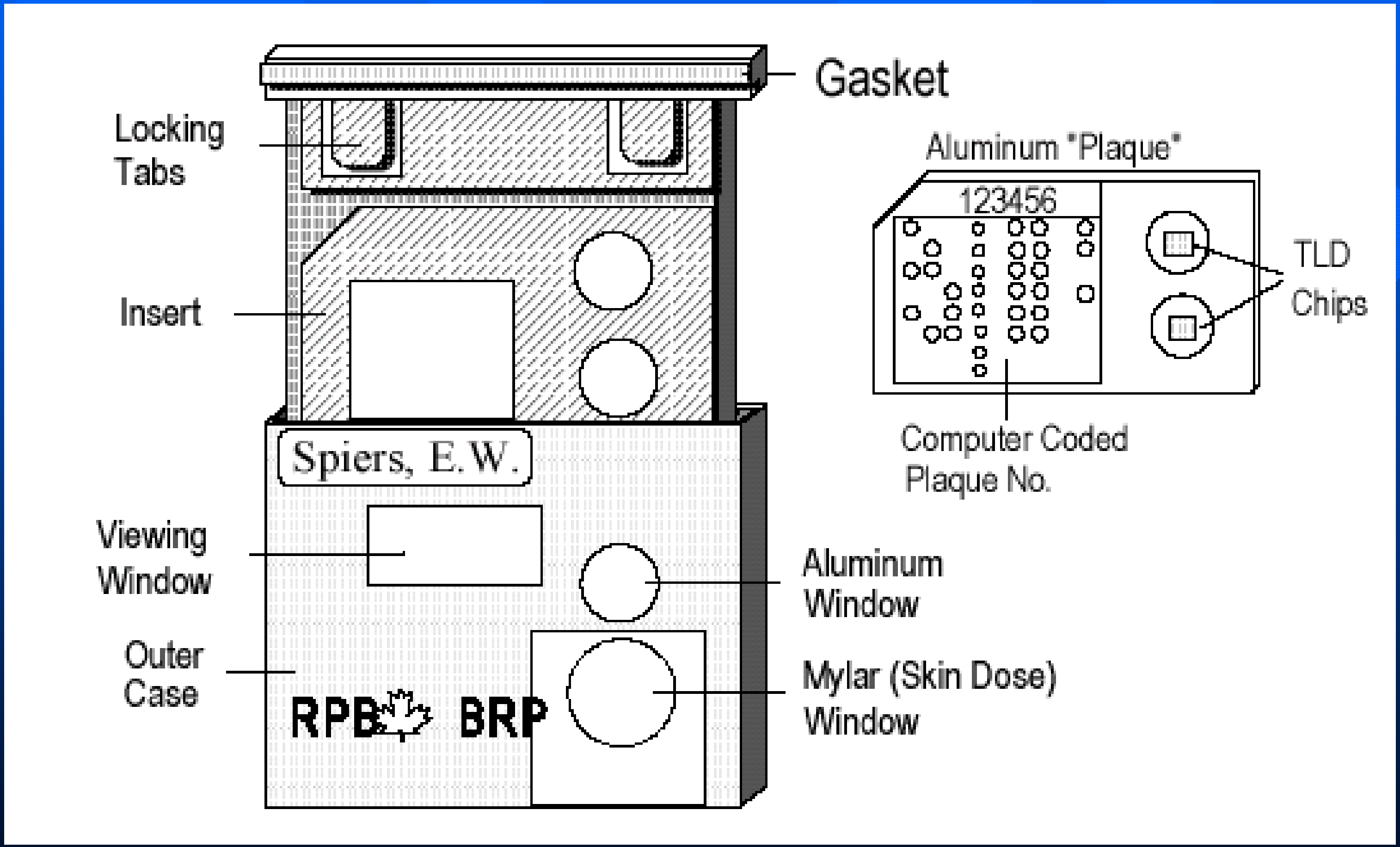
Thermo-luminescent dosimeters (TLD)

- TLD chips
  - Radiation => electrons are excited and trapped to certain energy levels in the material
  - Light is released by heating
  - Light is proportional to the amount of radiation absorbed by the TLD

Thermo-luminescent dosimeters (TLD)

- TLD Badges
  - Set of TLD chips in plastic holders with filters
  - 2 radiation windows
    - » Thin Mylar window (7 mg/cm^2) => skin dose
    - » Aluminum window (2 mm) => total body dose
  - Send every 3 months to National Dosimetry Service for analysis and report

Thermo-luminescent dosimeters (TLD)

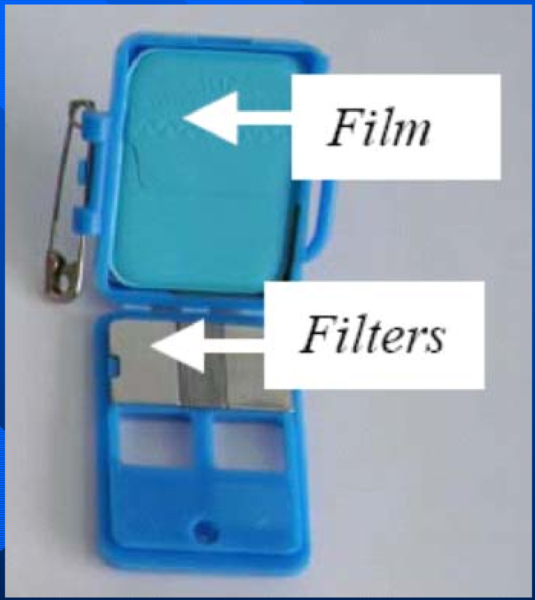


Thermo-luminescent dosimeters (TLD)

- Always wear *your own* all times while working
- Wear TLD's on chest area, *UNDER* protective clothing
- Wear extremity ring on most used hand, chip facing source
- Store away from radioactive sources
- DO NOT tamper with TLD chip or remove from holder
- Avoid subjecting to sunlight, high temperatures or wetness

Film Badges

- Alternative to TLD badge systems
- Photographic film covered by a set of filters
- Filters allow an assessment of the type of radiation involved
- Badges are returned to the monitoring service for development of the films
- Reading of the radiation dose from the optical density (opacity) of the film



Radiation Detection

Exposure

measure of: DOSE RATE

instrument: dose rate meter

measures in dose per unit time (e.g. Sv/hr, rem /hr)

Contamination Monitoring

measure of: ACTIVITY

instrument: contamination meter

measures in counts per unit time (e.g.CPS, CPM)

Direct

monitoring of surface

instrument: portable meter

detects fixed & loose

Indirect

monitoring of sample (wipe)

instrument: Liq. Scintillation or Gamma Counter

detects loose contamination

Portable Instruments

- At MUHC, portable survey instruments are used primarily for the detection of CONTAMINATION – the internal hazard.
- Instruments can be used to detect the presence of RADIATION – the external hazard, but cannot be used to accurately quantify it

Approximate detection efficiencies for some common radionuclides and detectors.

Radionuclide	LSC[1]	Pancake GM[2]	NaI(Tl) Meter[3]	NaI(Tl) Well[4]
H-3	20%	na[5]	na[5]	na[5]
C-14, S-35, P-33	50%	10%	na[5]	na[5]
Cr-51, Co-57, Tc-99m, I-125	30%	1%	50%	50%
P-32	100%	50%	na[5]	na[5]

LSC[1] : Liquid Scintillation Counter

PancakeGM[2] : Hand-held survey meter with pancake GM detector

NaI(Tl)[3] : Hand-held survey meter with well-type NaI(Tl) crystal

NaI(Tl)[4] : Multichannel analyzer with well-type NaI(Tl) crystal

na[5]: not applicable for this group of radionuclides

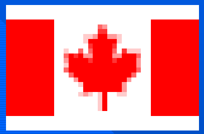
http://www.stanford.edu/dept/EHS/prod/researchlab/radlaser/manual/part3/surveys.htm

MODULE 5

Transport and handling of Radioactive Packages

Transport of Dangerous Goods

Transport Dangerous Goods (TDG) Directorate



-focal point for the national program to promote public safety during TDG

-major source of regulatory development, information and guidance on dangerous goods transport for the public, industry and government employees.

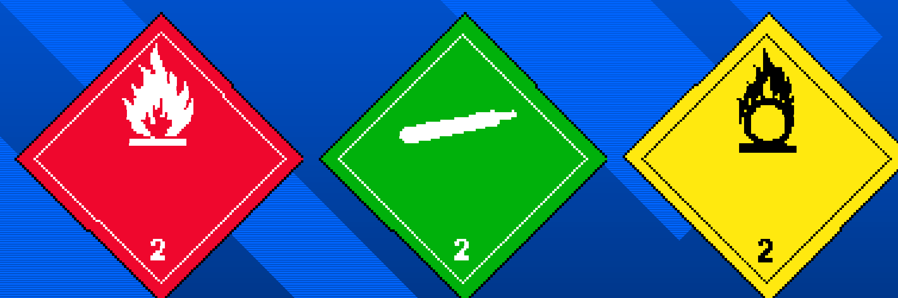
Transport of Dangerous Goods

- No person shall handle, offer for transport or transport DG **unless trained or work under supervision of a trained person**
- Person is trained if **employer is satisfied the employee has received adequate instructions** for the handling of DG
- Employer must ensure that trained persons have **certificate of training** (valid for 3 years)
- Employee required to **produce the TDG certificate if requested by the an inspector**

Classification of Dangerous Goods

Class 1: Explosives

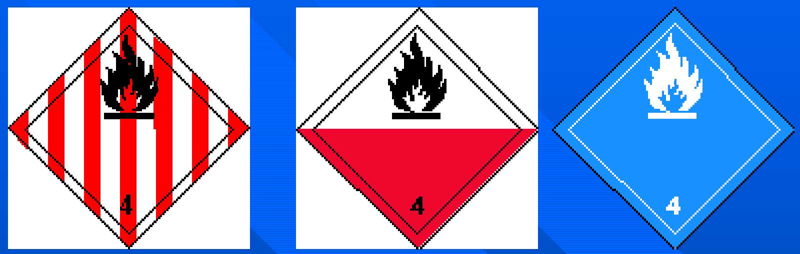
Class 2: Gases



Class 3: Flammable liquids

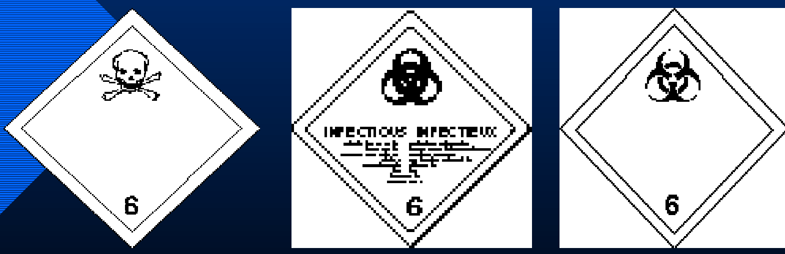
Classification of Dangerous Goods

Class 4: Flammable Solids



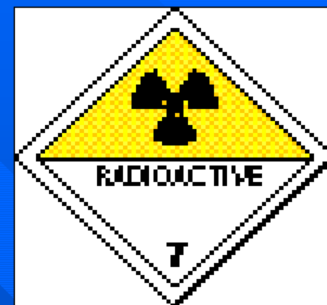
Class 5: Oxidizing Substances and Organic Peroxides

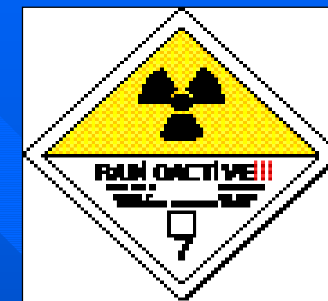
Class 6: Toxic and infectious substances



Classification of Dangerous Goods

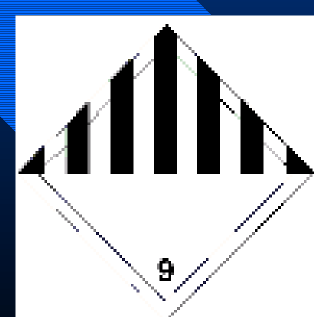
Class 7: Radioactive Materials





Class 8: Corrosives

Class 9: Miscellaneous Products, Substances or Organisms



Class 7: Radioactive Materials

Material emitting hazardous radiation (radioactive particles)

-uranium hexafluoride
-Thorium
-Iridium
-Tritium …

Class 7: Radioactive Materials

Radioactive packages may be shipped as:

- Excepted packages
- Industrial packages (for LSA material)
- Type A packages
- Type B (U) packages
- Type B (M) packages
- Type C packages

Marks and Labels

When handling or receiving radioactive materials the following proper shipping names and UN numbers may be observed (partial list only):

UN 2910 Radioactive material, excepted package, instruments

UN 2910 Radioactive material, excepted package, articles

UN 2910 Radioactive material, excepted package, limited quantity of material

UN 2910 Radioactive material, excepted package, empty packaging

UN 2912 Radioactive material, low specific activity (LSA)

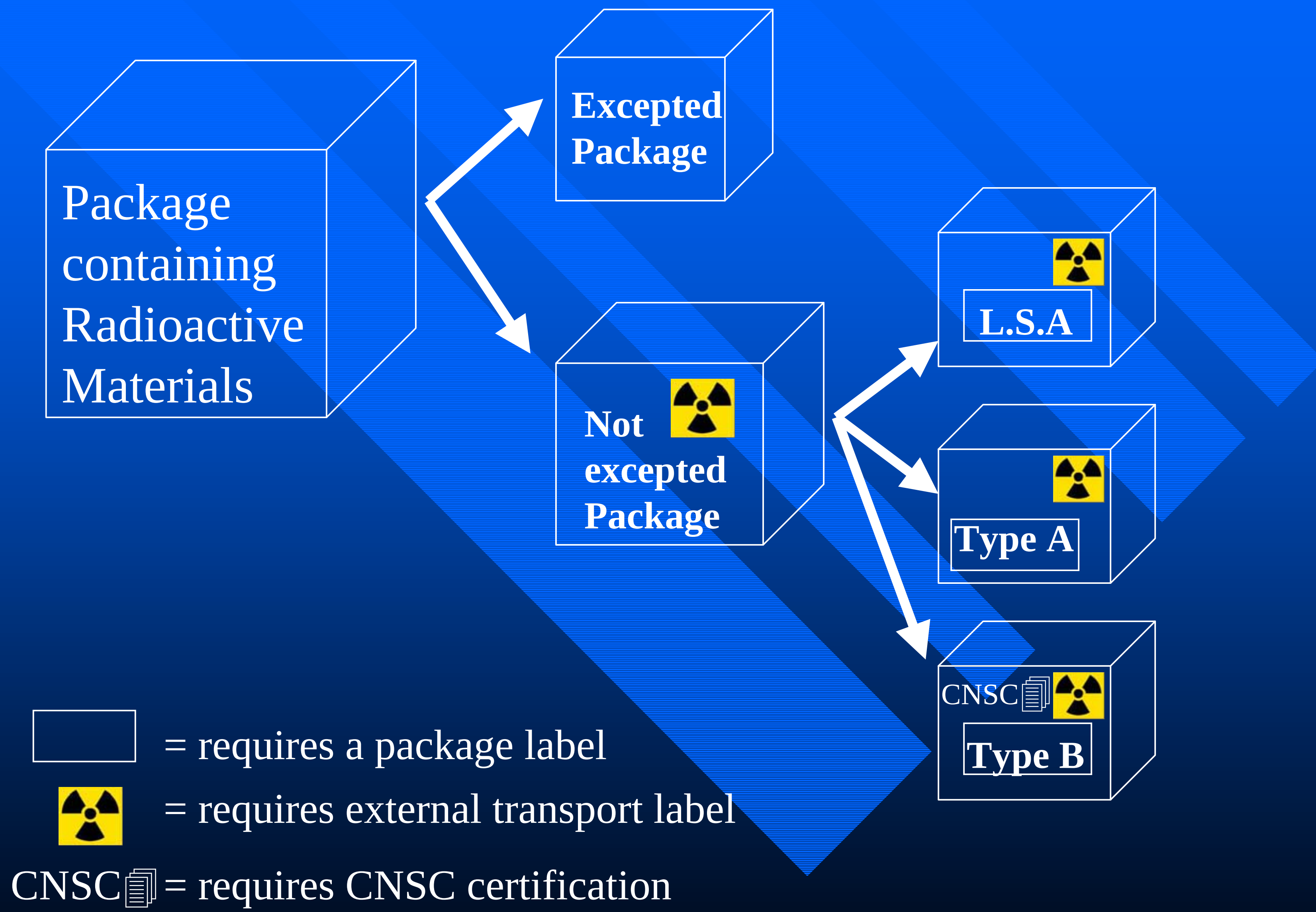
UN 2915 Radioactive material, Type A package, non-special form, non fissile or fissile excepted

Class 7: Radioactive Materials

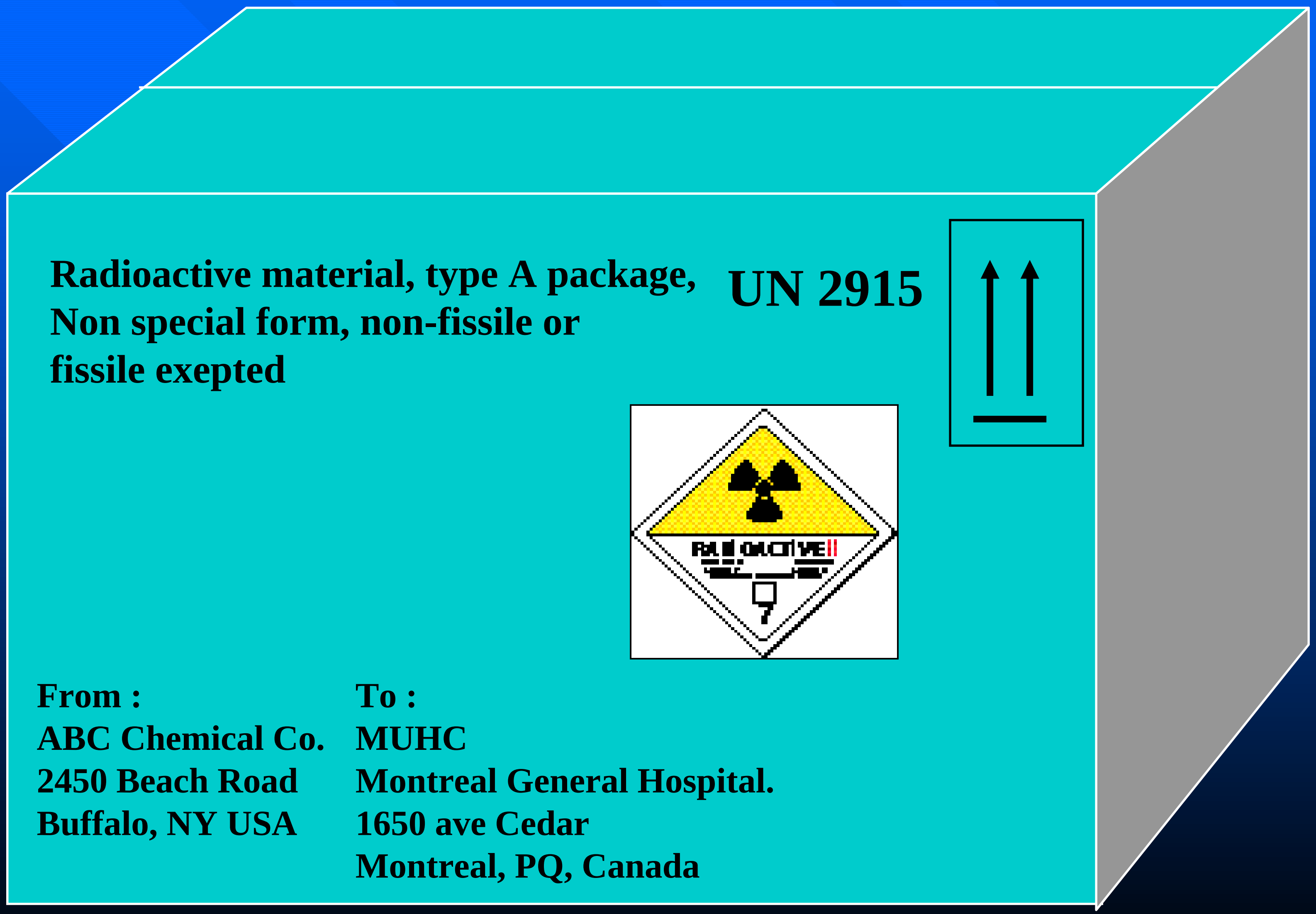
- EXCEPTED PACKAGES
  - Contains **very low activities**, very low hazard (ex. Calibration source sent to a high school)
  - **No special marking** (could be a small cardboard box)
  - The safety mark radioactive must be visible on opening the package
  - All other packages must be categorized by radiation level and display the corresponding radiation warning labels

Class 7: Radioactive Materials

- TYPE A PACKAGES
  - Contains medium activities of radioactive materials (ex. Radioisotope shipped to Hospital)
  - Hazard in event of accident controlled by the limits and amount shipped
  - Package may be metal, plywood, cardboard box or drum + foam inserts
  - Package will have labels
  - Transport vehicle requires placarding

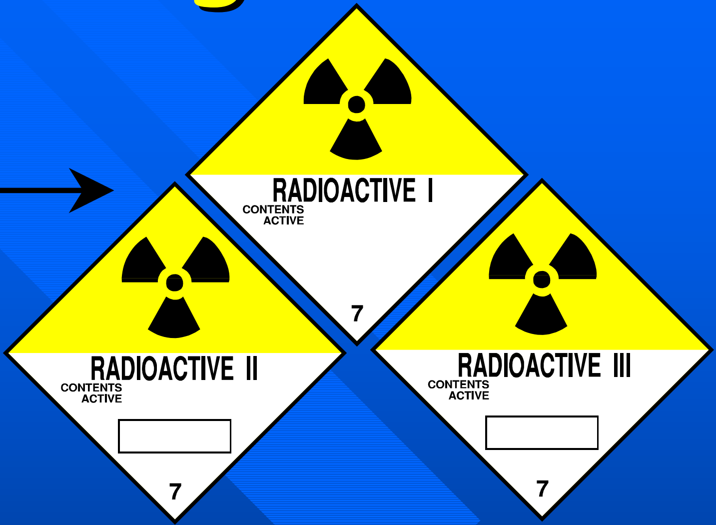

Package containing Radioactive Materials
Excepted Package
Not excepted Package
L.S.A
Type A
CNSC
Type B
= requires a package label
= requires external transport label
CNSC = requires CNSC certification

Marks and Labels



Vehicle Placarding

Transportation Placards
And Labels



Class 7 : Categories

Category I - WHITE

- Activity> excepted activity
- < $5 \mu Sv/h$ at external surface
- Transport index < 1

Category II - YELLOW

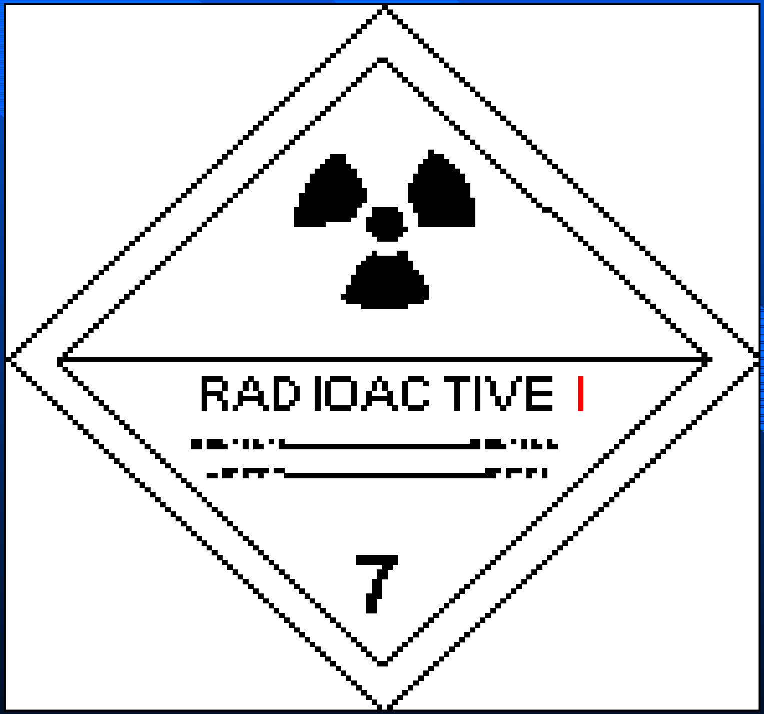
- Activity > excepted activity
- < $500 \mu Sv/h$ at external surface
- Transport index < 1

Category III - YELLOW

- Activity > excepted activity
- < $2000 \mu Sv/h$ at external surface
- Transport index < 10

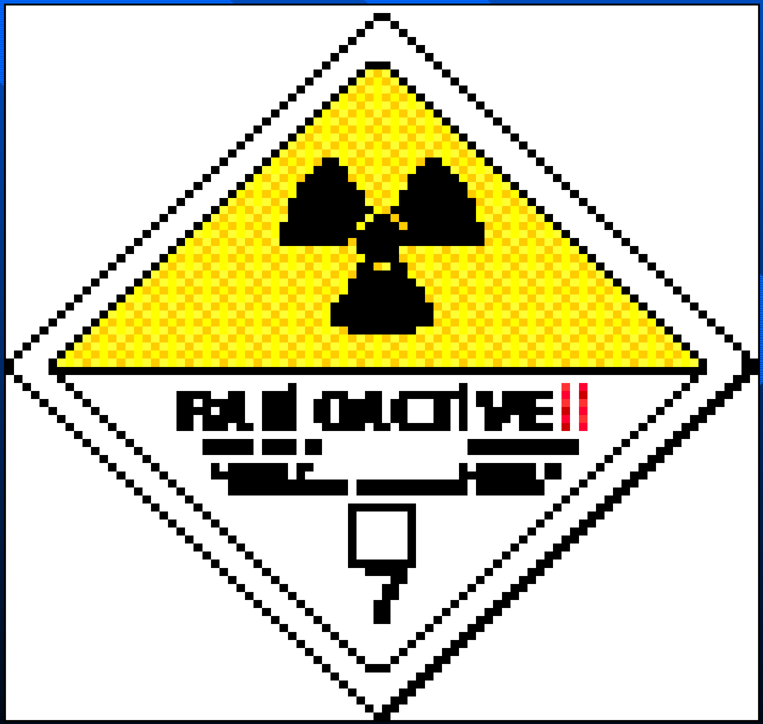
Class 7 : Categories

- Category I
  - No more 5 μSv/h (surface)



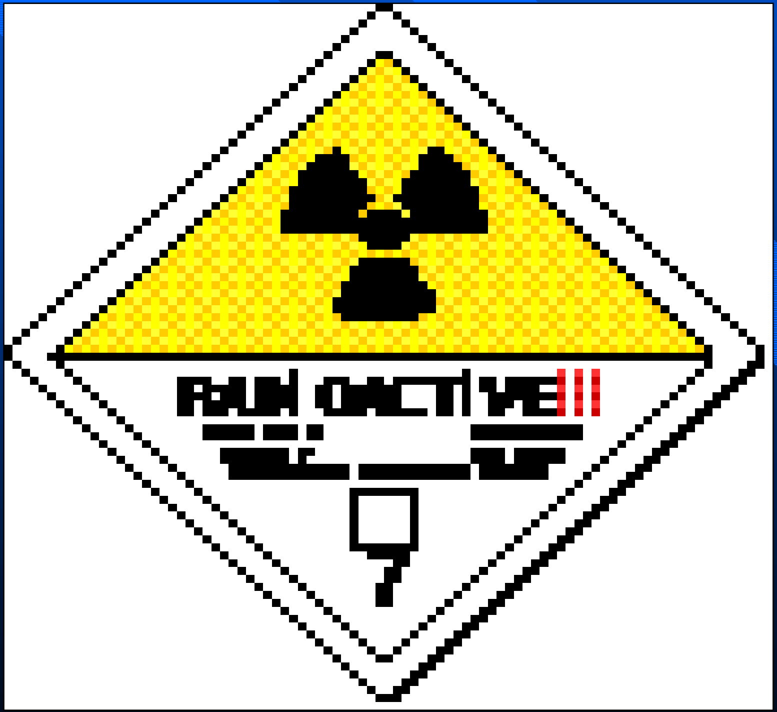
Class 7 : Categories

- Category II
  - More then 5 μSv but no more than 0.5 mSv/h (surface)



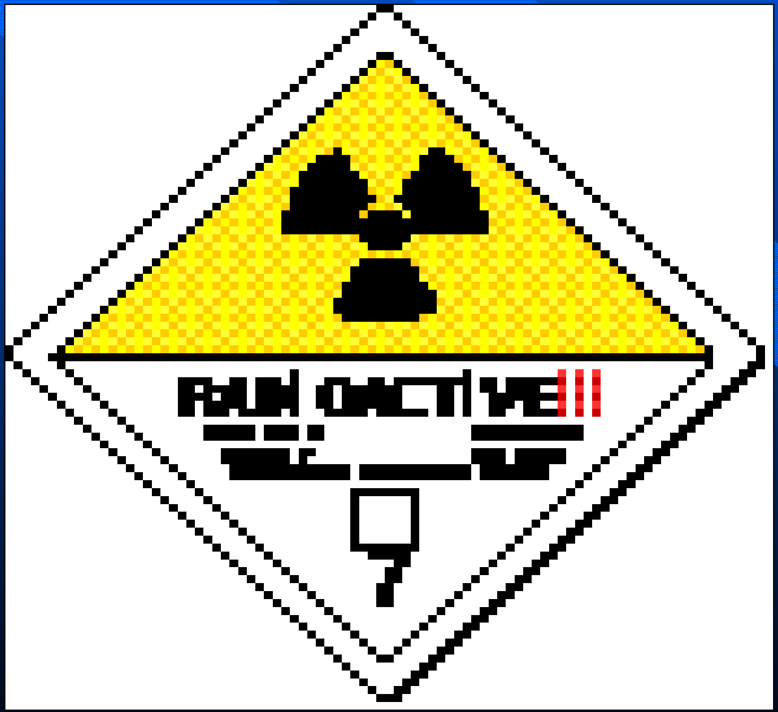
Class 7 : Categories

- Category III
  - More than 0.5 mSv/h, but no more than 2 mSv/h (surface)



Class 7 : Categories

- Category III (exclusive use)
  - More than 2 mSv/h, but no more than 10 mSv/h



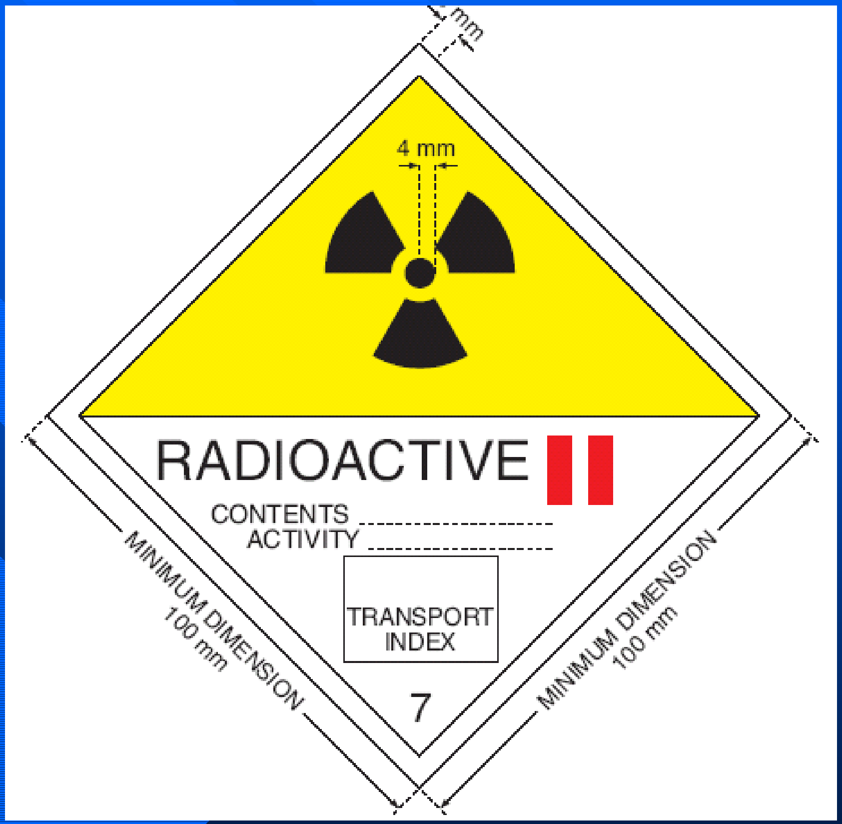
Class 7 : Labels

Contents

Activity (in Bq)

Transport Index (T.I.)

White I = no transport index
Yellow II = TI between 0-1
Yellow III= TI between 1-10



T.I. = (dose rate in *mSv/h*) x 100 @ 1 meter

Receipt of Radioactive Material

- Wear a Lab coat and disposable gloves
- Monitor radiation field
- Place in fume hood if volatile material
- Open outer package, check for possible damage
- Remove inner package, wipe test container
- Verify the radioisotope, activity … with information on waybill
- **Report any anomalies to the supervisor or RSO**

See INFO-0426/rev1

Shipper AMERSHAM BIOSCIENCE
3350 N RIDGE AVE
ARLINGTON HEIGHTS IL 60004

Air Waybill No. 4993 2713 2710

Page 1 of 1 Pages

Shippers Reference Number 969740

Consignee
ROYAL VICTORIA HOSPITAL
687 PINE AVENUE WEST
MOLECULAR ONCOLOGY GROUP
MONTREAL, PQ H3A1A1
CANADA

Two completed and signed copies of this declaration must be handed to operator

WARNING
Failure to comply in all respects with the applicable Dangerous Goods Regulations may be in breach of this applicable law, subject to legal penalties. This Declaration must not, in any circumstances, be completed and/or signed by a consolidator, a forwarder or an IATA cargo agent

TRANSPORT DETAILS

This shipment is within the limitations prescribed for: (delete non-applicable)

PASSENGER AND CARGO AIRCRAFT	~~CARGO AIRCRAFT ONLY~~	Airport of Departure: CHICAGO

Airport of Destination

Shipment type: (delete non-applicable)

~~NON-RADIOACTIVE~~	RADIOACTIVE

NATURE AND QUANTITY OF DANGEROUS GOODS (*see Sub-section 8.1 of IATA Dangerous Goods Regulations*)

Dangerous Goods Identification							
Proper Shipping Name	Class or Divison	UN or ID No.	Packing Group	Subsidairy Risk	Quantity and type of Packing	Packing Instructions	Authorization
RADIOACTIVE MATERIAL TYPE A PACKAGE	7	UN2915			PHOSPHORUS-32 Liquid Organic Compound ALL PACKED IN 1 TYPE A PACKAGE 519.468 MBq (14.040 mCi)	YELLOW II T.I. 0.1 DIMENSIONS 26 x 17 x 12CM	

Additional Handling Information ICAO / IATA

MATERIAL INTENDED FOR RESEARCH OR MEDICAL TREATMENT

24 hr. Emergency contact Tel. No 800-584-9333

I hereby declare that the contents of this consignment are fully and accurately described above by proper shipping name and are classified, packed, marked and labeled, and are in all respects in the proper condition for transport by air according to the applicable international and National Government Regulations.

Name/Title of Signatory JEFF MAJEWSKI EXPORT CLERK

Place and Date CHICAGO 11/25/2002

Signature (see warning above) J. Majewski

SD-191

Shipper AMERSHAM BIOSCIENCE 3350 N RIDGE AVE ARLINGTON HEIGHTS IL 60004	Air Waybill No. 4993 2713 2710 Page 1 of 1 Pages Shippers Reference Number 969740
Consignee ROYAL VICTORIA HOSPITAL 687 PINE AVENUE WEST MOLECULAR ONCOLOGY GROUP MONTREAL, PQ H3A1A1 CANADA	
Two completed and signed copies of this declaration must be handed to operator	**WARNING** Failure to comply in all respects with the applicable Dangerous Goods Regulations may be in breach of this applicable law, subject to legal penalties. This Declaration must not, in any circumstances, be completed and/or signed by a consolidator, a forwarder or an IATA cargo agent

TRANSPORT DETAILS

This shipment is within the limitations prescribed for: (delete non-applicable)		Airport of Departure
PASSENGER AND CARGO AIRCRAFT	~~CARGO AIRCRAFT ONLY~~	CHICAGO

Airport of Destination

Shipment type: (delete non-applicable)

~~NON-RADIOACTIVE~~	RADIOACTIVE

NATURE AND QUANTITY OF DANGEROUS GOODS (*see Sub-section 8.1 of IATA Dangerous Goods Regulations*)

Dangerous Goods Identification					Quantity and type of Packing	Packing Instructions	Authorization
Proper Shipping Name	Class or Divison	UN or ID No.	Packing Group	Subsidiary Risk			

Dangerous Goods Identification					Quantity and type of Packing	Packing Instructions	Authorization
Proper Shipping Name	Class or Divison	UN or ID No.	Packing Group	Subsidairy Risk			
RADIOACTIVE MATERIAL TYPE A PACKAGE	7	UN2915			PHOSPHORUS-32 Liquid Organic Compound ALL PACKED IN 1 TYPE A PACKAGE 519.468 MBq (14.040 mCi)	YELLOW II T.I. 0.1 DIMENSIONS 26 x 17 x 12CM	

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Name/Title of Signatory EXPORT CLERK
JEFF MAJEWSKI
Place and Date 11/25/2002
CHICAGO
Signature (see warning above) J. Majewski

SHIPPER'S DECLARATION FOR DANGEROUS GOODS

(Provide at least two copies to the airline.)

Shipper
PerkinElmer Life Sciences
549 Albany Street
Boston, MA 02118

Air Waybill No. 81468640 374

Page 1 of 1 Pages

Shipper's Reference Number *(optional)*

Consignee
HOSP ROYAL VICTORIA
UNIV CLINIC
687 AVE PINS O
MONTREAL PQ
CANADA H3A 1A1

YUC

Two completed and signed copies of this Declaration must be handed to the operator

TRANSPORT DETAILS

This shipment is within the limitations prescribed for: *(delete non-applicable)*

PASSENGER AND CARGO AIRCRAFT	~~CARGO AIRCRAFT ONLY~~

Airport of Departure: BOSTON

Airport of Destination: MONTREAL

WARNING

Failure to comply in all respects with the applicable Dangerous Goods Regulations may be in breach of the applicable law, subject to legal penalties. This Declaration must not, in any circumstances, be completed and/or signed by a consolidator, a forwarder or an IATA cargo agent.

Shipment type: *(delete non-applicable)*

~~NON-RADIOACTIVE~~	RADIOACTIVE

NATURE AND QUANTITY OF DANGEROUS GOODS

Proper Shipping Name, Class or Division, UN Number or Identification Number, Packing Group (if required), number of packages, and all other required information.

Radioactive material, Type A package, 7, UN2915//
S-35, Liquid/Salt, 1 Type A package x0.310762GBq//I-White//#051027893 2

Additional Handling Information

Entries comply with IATA/ICAO ---- This Shipment is to be used in medical research having direct application to HUMAN medical welfare.

24 hr. Emergency Contact Tel. No. (703)527-3887

I hereby declare that the contents of this consignment are fully and accurately described above by the proper shipping name and are classified, packaged, marked and labelled/placarded, and are in all respects in proper condition for transport according to applicable international and national governmental regulations.

Name/Title of Signatory: EWAN STEPHENS EXP REP

Place and Date: BOSTON, Ma 08-APR-2003

Signature *(see warning above)*

SHIPPER'S DECLARATION FOR DANGEROUS GOODS (Provide at least two copies to the airline.)

Shipper PerkinElmer Life Sciences 549 Albany Street Boston, MA 02118	Air Waybill No. 81468640 374 Page 1 of 1 Pages Shipper's Reference Number *(optional)*
Consignee HOSP ROYAL VICTORIA UNIV CLINIC 687 AVE PINS O MONTREAL PQ CANADA H3A 1A1	YUC
Two completed and signed copies of this Declaration must be handed to the operator	**WARNING** **Failure to comply in all respects with the applicable Dangerous Goods Regulations may be in breach of the applicable law, subject to legal penalties. This Declaration must not, in any circumstances, be completed and/or signed by a consolidator, a forwarder or an IATA cargo agent.**

TRANSPORT DETAILS

This shipment is within the limitations prescribed for: *(delete non-applicable)*

PASSENGER AND CARGO AIRCRAFT	~~CARGO AIRCRAFT ONLY~~

Airport of Departure: BOSTON

Airport of Destination: MONTREAL

Shipment type: *(delete non-applicable)*

~~NON-RADIOACTIVE~~	RADIOACTIVE

NATURE AND QUANTITY OF DANGEROUS GOODS

Proper Shipping Name, Class or Division, UN Number or Identification Number, Packing Group (if required), number of packages, and all other required information.

Radioactive material,Type A package,7,UN2915//

S-35,Liquid/Salt,1 Type A package x0.310762GBq//I-White//#051027893 2 and all other required information.

Radioactive material, Type A package, 7, UN2915//
S-35, Liquid/Salt, 1 Type A package x0.310762GBq//I-White//#051027893 2

Additional Handling Information

Entries comply with IATA/ICAO ---- This Shipment is to be used in medical research having direct application to HUMAN medical welfare.

24 hr. Emergency Contact Tel. No. (703)527-3887

I hereby declare that the contents of this consignment are fully and accurately described above by the proper shipping name and are classified, packaged, marked and labelled/placarded, and are in all respects in proper condition for transport according to applicable international and national governmental regulations.

Name/Title of Signatory
EWAN STEPHENS EXP REP

Place and Date
BOSTON, Ma
02-APR-2003

Signature
(see warning above)

Receipt of Radioactive Material

Remove or deface all radiation warning symbols prior discarding the box in the normal waste stream

Certificate of Training
Transportation of Dangerous Goods

Name of Employer: **McGill University Health Center (MUHC)**
1650 avenue Cedar, Montreal, PQ, Canada

Name of Employee:

This certificate certifies that the employee named above has completed the training for the *Safe Handling and Transportation Practices, and the Characteristics of Dangerous Goods* (class 7, radioactive materials), in accordance with the requirements of the Transportation of Dangerous Goods Act and Regulations.

Certificate expires on:

Employee's signature:

Supervisor's signature:

RSO's signature:

MODULE 6

Working in Laboratories

CLASSIFICATION OF LABORATORY

Exemption Quantity (EQ)

The quantity, in becquerel (Bq), of a radionuclide below which **no licence is required**

Isotope	EQ (MBq)
H-3	1000
C-14	100
P-32	0.01
P-33	1
S-35	100
Cr-51	1

RADIOISOTOPE	EXEMPTION QUANTITIY (EQ)	
	MBq	µCi
H-3	1000	27000
P-32	0.01	0.27
P-33	1.0	27
S-35	100	2700
I-125	1.0	27
I-131	0.01	0.27
C-14	100	2700
Cr-51	1	27

CLASSIFICATION OF LABORATORY

Annual Limit of Intake (ALI)

The activity, in becquerel (Bq), of a radionuclide that will deliver an effective dose of 20 mSv after the radionuclide is taken into the body

Basic:	5	X	ALI
Intermediate:	5-50	X	ALI
High:	50-500	X	ALI

> 10,000 EQ:

Requires written approval from CNSC

RADIOISOTOPE	BASIC LEVEL		INTERMEDIATE LEVEL	
	MBq	mCi	MBq	mCi
H-3	5000	135	50000	1350
P-32	40	1.08	400	10.8
P-33	400	10.8	4000	108.1
S-35	130	3.5	1300	35.1
I-125	5	0.135	50	1.35
I-131	5	0.135	50	1.35
C-14	170	4.59	1700	45.9
Cr-51	2650	71.6	26500	716

CLASSIFICATION OF RADIONUCLIDES

Class A: Na-22, Co-60, Zn-65, ...

Class B: Fe-59, Rb-86, ...

Class C: H-3, C-14, P-32, P-33, S-35, Ca-45, I-125, ...

Contamination Criteria	**Decommissioning Criteria**
Class A : 3 Bq/cm^2	Class A : 0.3 Bq/cm^2
Class B : 30 Bq/cm^2	Class B : 3 Bq/cm^2
Class C : 300 Bq/cm^2	Class C : 30 Bq/cm^2

Basic Level

- Do not eat, drink, store food or smoke
- In case of spill, follow spill procedure
- Clearly identify work surfaces for handling nuclear substances
- Check all packages containing nuclear substances for damage upon receipt
- Store nuclear substances in a locked room or enclosure when not in use
- Monitor laboratory for removable contamination weekly and keep records

Radioisotope Lab
Laboratoire de radioisotopes

Room: AA-123

Basic
Élémentaire

RESPONSIBLE / RESPONSABLE
John Smith
Local: AA-123 Tel: 12345

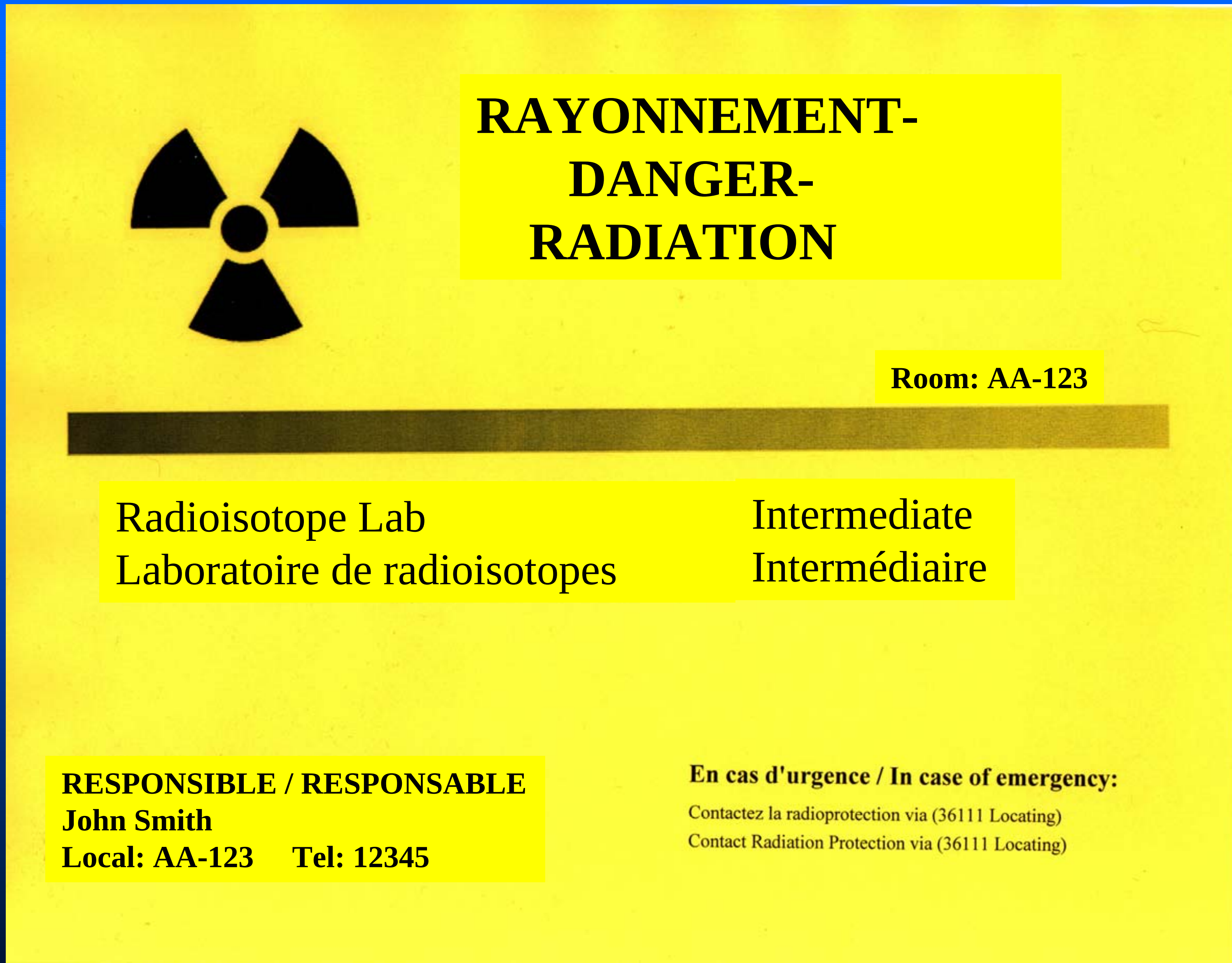
En cas d'urgence / In case of emergency:

Contactez la radioprotection via (36111 Locating)
Contact Radiation Protection via (36111 Locating)

Intermediate Level

Basic level Procedures plus :

- Wear appropriate dosimeters at all times
  - » Extremity dosimeter required to handle more than 50 MBq of P-32, Sr-90, Y-90, Sm-153, Re-186
- After working with NS, monitor work area for contamination


RAYONNEMENT-
DANGER-
RADIATION
Room: AA-123
Radioisotope Lab
Laboratoire de radioisotopes
Intermediate
Intermédiaire
RESPONSIBLE / RESPONSABLE
John Smith
Local: AA-123 Tel: 12345
En cas d'urgence / In case of emergency:
Contactez la radioprotection via (36111 Locating)
Contact Radiation Protection via (36111 Locating)

High Level

Intermediate level Procedures plus :

- Restrict access to authorized personnel
- Work in fumehood when required by RSO
- Wash hands regularly and monitor them for contamination


RAYONNEMENT-
DANGER-
RADIATION
Room: AA-123
Radioisotope Lab
Laboratoire de radioisotopes
HIGH LEVEL
Niveau Supérieur
RESPONSIBLE / RESPONSABLE
John Smith
Local: AA-123 Tel: 12345
En cas d'urgence / In case of emergency:
Contactez la radioprotection via (36111 Locating)
Contact Radiation Protection via (36111 Locating)

LABELING AND SIGNS

- Use the words

RAYONNEMENT
DANGER
RADIATION

If quantity is > 100 EQ or
If effective dose rate > 20 μSv/h

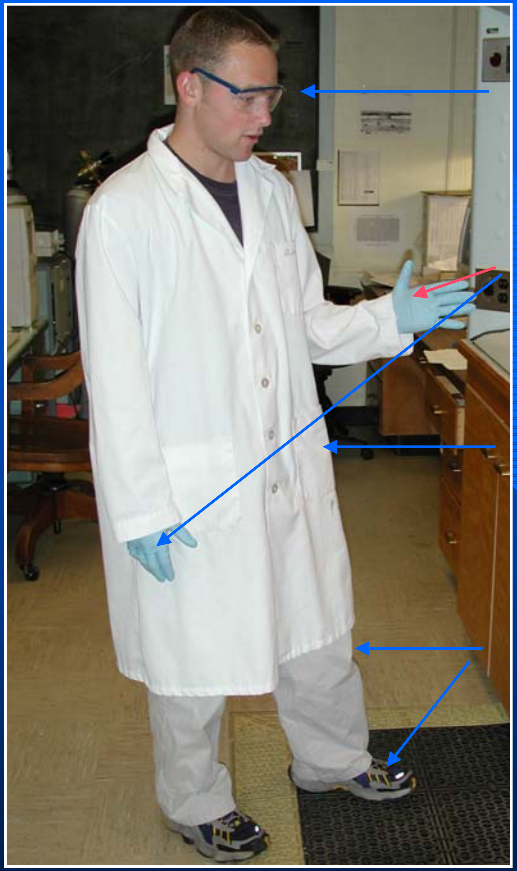
LABELING AND SIGNS

- **Frivolous Posting of signs**
  - No person shall post a radiation sign (trefoil) at a place where radiation, nuclear substances or prescribed equipment is NOT present
  - **For pencil, rulers, calculators, pipettes, etc … use any signs BUT the trefoil**

Happy face will do fine !

Personal Protective Equipment

Required for using Radioisotopes



Full Length Dresses or Pants ONLY

Eye Protection

Latex Gloves

Lab Coat

Complete Coverage Feet and Legs

- No Shorts
- No Half Shorts
- No Open-Toed Shoes
- No Mini-Skirts

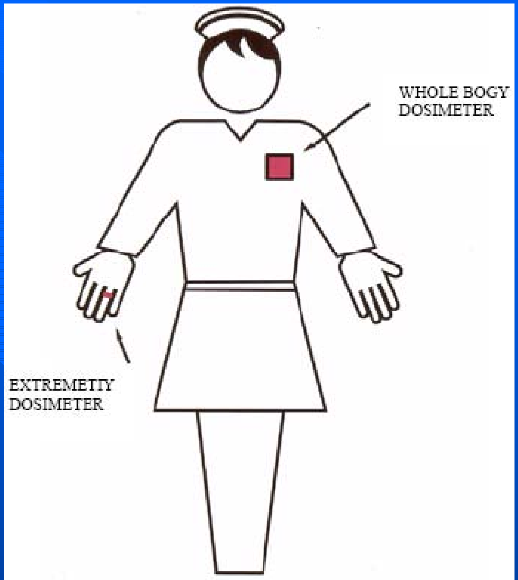
- PPE is worn on the body
- Primary purpose is to provide a barrier to radioactive materials or radiation

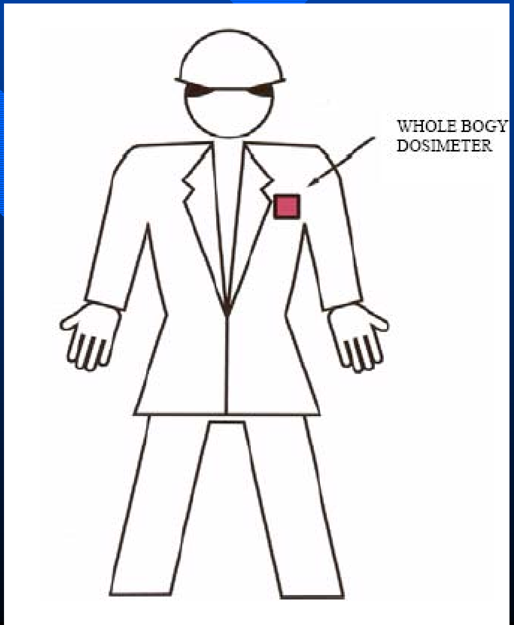
Personal Dosimeters

- Do not expose TLD to high temperature, water, sunlight

- Clip firmly between waist and neck
- Extremity TLDs (rings) facing the source
- If you loose your TLD, you should stop working until you receive a replacement

- Store in holder or rack when not in use
- Store in low radiation area away from light and heat





Ring TLD

Body TLD

Measuring Surface Contamination

- Two Methods:
  - The Direct Method Uses a pancake type probe, or thin walled Geiger tube to measure both fixed and loose contamination

  - The Indirect Method Uses swipes to test for loose contamination

The Direct Method

1.Select a slow response time and measure the background well away from the surface to be monitored

2. Select a fast response time, and pass the detector slowly over the surface at a distance of about 1 cm

3. Hold the probe over the detected area long enough to obtain a steady reading

4. Subtract the background rate from this reading and compare this result to the count rate corresponding to 1 CCL

Pro's and Con's

- **Disadvantages:**
  - It is impossible to make a direct measurement of surface contamination when a high gamma field is present
  - will not distinguish between loose and fixed contamination
- **Advantages:**
  - Measures the radiation level from both fixed and removable contamination

The Indirect method

1. Select the surface to be swiped
2. Identify the swipe paper to be used
3. Swipe an area of about 100 cm^2 using light pressure
4. Put each swipe in separate envelope to prevent cross contamination
5. Measure the background count
6. Measure the activity of the swipe
7. The difference between the two readings is due to radioactivity picked up by the swipe

Pro's and Con's

- Disadvantages:
  - Only 10% of the contamination will be picked up
  - If the surface is wet the swipe needs to dry first
  - Heavily contaminated swipes can lead to dead time losses in the detector
- Advantages:
  - Swipes measure loose contamination only
  - They can be taken to a low background location to be measured

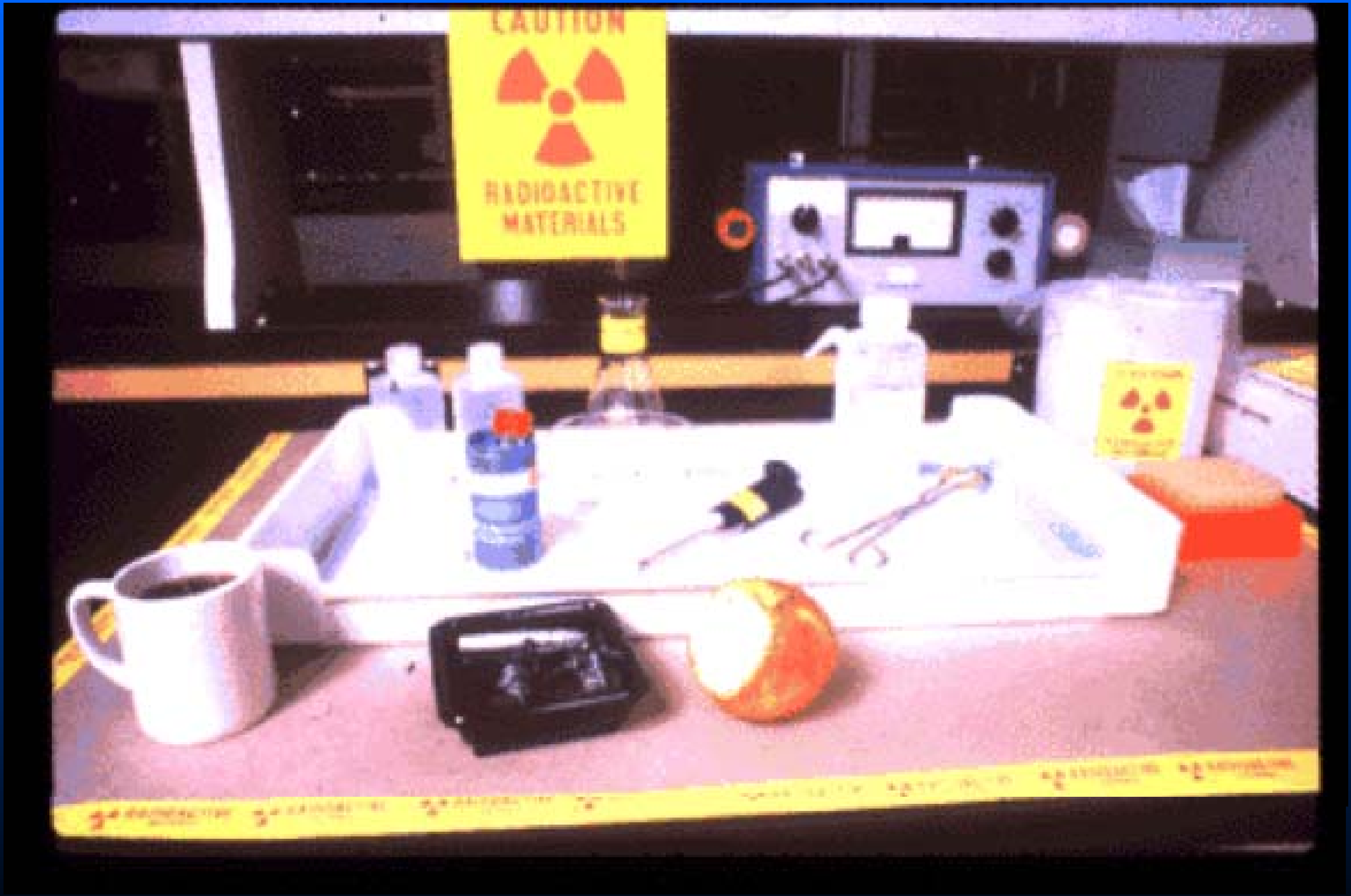
RAD TAPE

Work area delineated with rad tape

Use shield if available (ALARA)

Monitor for contamination when finished

Find the Errors



Find the Errors

What to do to protect yourself....

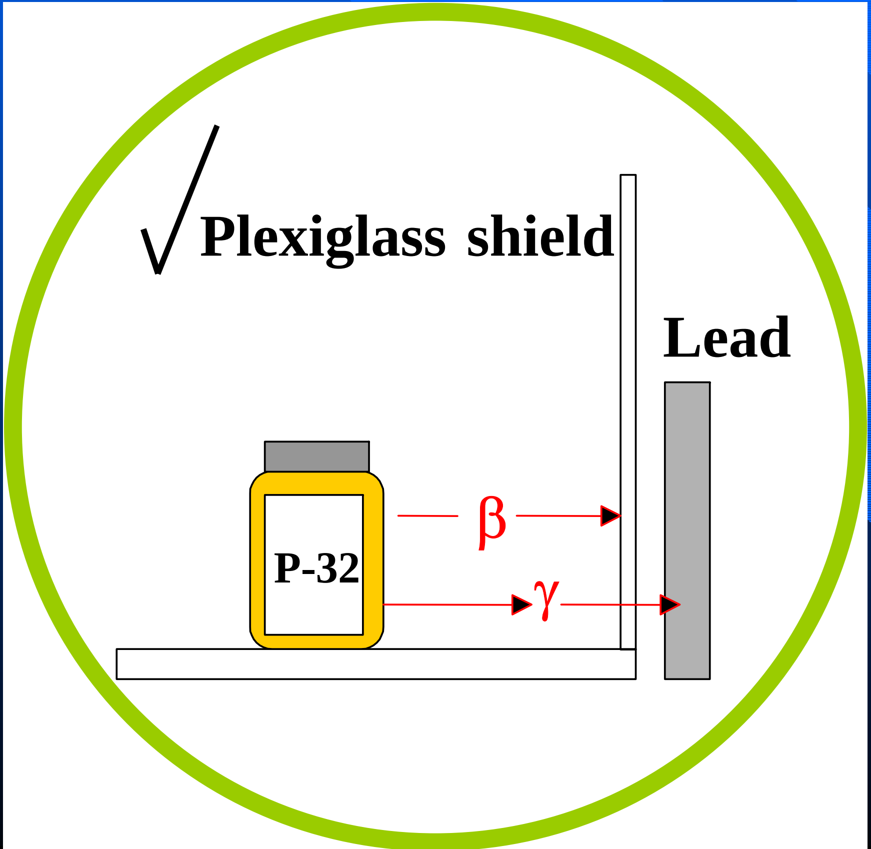
Basic Radiation Safety Principles for External Radiation

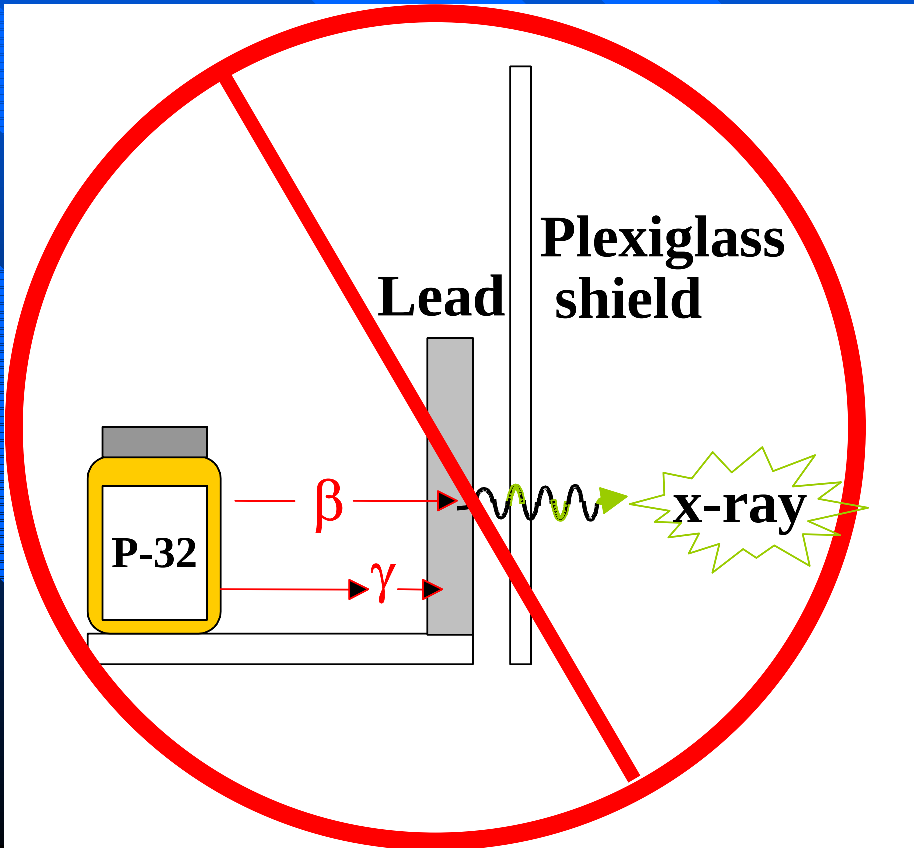
- Time
- Distance
- Shielding*

Work behind plexiglass shield when manipulation beta emitters

Shielding Beta Radiation

- Low density materials (ie. plexiglass) must be used to shield beta radiation because...
- Interaction with dense materials produces Bremsstrahlung





Inventory Control

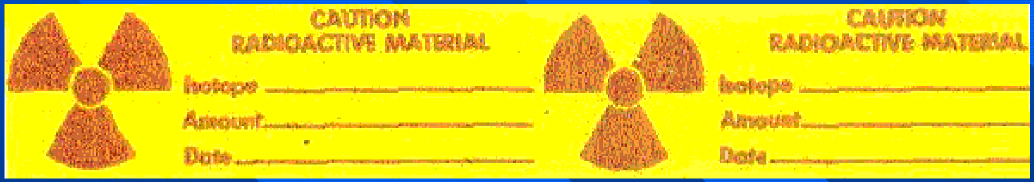
- Ordering radioactive material
  - Only permit holders or authorized personnel can order radioisotopes
  - Register new vials on the McGill Radioisotope Tracking System (RTS)
- Inventory and disposal
  - 2 methods
    - RTS (entered daily)
    - Paper inventory (daily) before filing to RTS

Inventory Control

- Acquisition, control and storage
  - Only permit holders or authorized personnel can order **radioactive materials**
  - must be entered and tracked on the McGill **Radioisotope Tracking System (RTS)**
  - must be tracked after each use on RTS system (new vial record)

Inventory Control

- **Byproducts** created during handling which requires storage must be tracked also and labeled (user name, radionuclide, activity, date)



- Waste containers are also tracked by the RTS system
  - 1 isotope per container
  - Separate containers for liquid, solid, LSV

Inventory Control

- Alternative Tracking (Forms)
  - Running Log
  - By-product form
  - waste inventory form
- Forms
  - Must include the ID numbers assigned by RTS
  - Must be posted on the storage unit
  - Information must be entered on the RTS system every week

Radioisotope Running Log Form

Radioisotope & Product: ______________ Date of Measured Activity: _____________ Volume: ____________________________

Activity: ___________________________ Vial ID: ____________________________ Date of Reception: ____________________

Date	User	Activity Removed (uCi)	Volume Removed (ul)	Activity Remaining (uCi)	By Product ID	By Product RTS code	Liquid Waste (uCi)	Solid Waste (uCi)	Date of Disposal

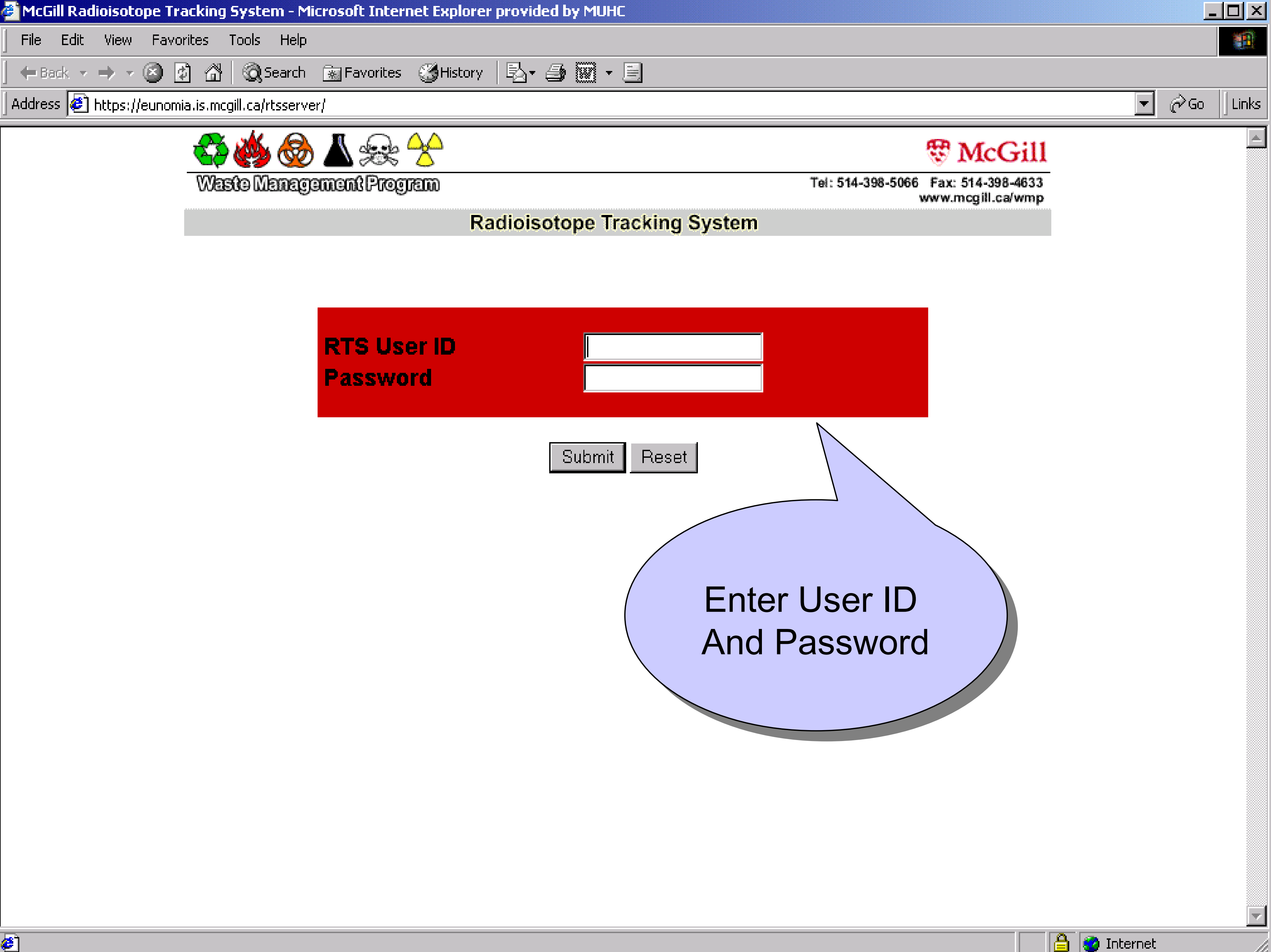
Disposed by: _________________________ Date of disposal of vial: ______________ Activity disposed: ____________________

McGill Radioisotope Tracking System (RTS)

- Web application to manage the use of radioisotope and the disposal of waste.
- Assigns a unique ID to vials
- Tracks the usage while calculating decay
- Enables the disposal through the proper waste containers

View the RTS web course online at :

http://www.mcgill.ca/eso/training/presentations/#1


McGill Radioisotope Tracking System - Microsoft Internet Explorer provided by MUHC
File Edit View Favorites Tools Help
Back Search Favorites History
Address https://eunomia.is.mcgill.ca/rtsserver/
Go Links
McGill
Waste Management Program
Tel: 514-398-5066 Fax: 514-398-4633
www.mcgill.ca/wmp
Radioisotope Tracking System
RTS User ID
Password
Submit Reset
Enter User ID
And Password
Internet

Radioisotope Tracking System - Microsoft Internet Explorer provided by MUHC

File Edit View Favorites Tools Help

Back Search Favorites History

Address https://eunomia.is.mcgill.ca/rtsserver/wc.dll?RTSprocess~RTSLogOn Go Links

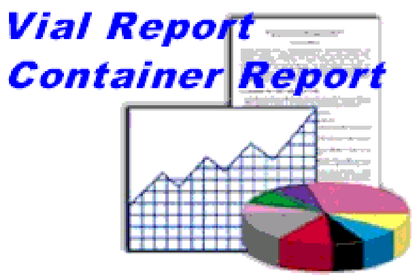
Waste Management Program

McGill

Tel: 514-398-5066 Fax: 514-398-4633
www.mcgill.ca/wmp

Radioisotope Tracking System

Licence Holder	Licence Holder Inventory		
	Radioisotope Vials	In Progress	Waste Containers
Licence #: 5-0038-03 ROYAL VICTORIA HOSPITAL MS MAUREEN MCQUEEN RADIATION PROTECTION 842-1231 EXT 36133			



Create New Vial

Done Internet

Radioisotope Tracking System - Microsoft Internet Explorer provided by MUHC

File Edit View Favorites Tools Help

Back Search Favorites History

Address https://eunomia.is.mcgill.ca/rtsserver/wc.dll?rtsprocess~NewVial Go Links

Waste Management Program

McGill

Tel: 514-398-5066 Fax: 514-398-4633
www.mcgill.ca/wmp

Radioisotope Tracking System

Licence Holder	Vial Data		
Licence #: 5-0038-03 ROYAL VICTORIA HOSPITAL MS MAUREEN MCQUEEN RADIATION PROTECTION 842-1231 EXT 36133	Order Number	001test	(Ref.No.,Purchase Order,Delivery #)
	Date Received	2004/10/14	(YYYY/MM/DD)
	Supplier	muhc	

Qty.	Isotope	Compos.	Activity		Vol.[mL]	Ref.Date
1	P-32	liquid	0.01	uCi	0.050	2000/01/01
	-Select-			uCi		YYYY/MM/DD
	-Select-			uCi		YYYY/MM/DD
	-Select-			uCi		YYYY/MM/DD
	-Select-			uCi		YYYY/MM/DD

Save Reset

Done Internet

Radioisotope Tracking System - Microsoft Internet Explorer provided by MUHC

File Edit View Favorites Tools Help

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Address https://eunomia.is.mcgill.ca/rtsserver/wc.dll?RTSprocess~RTSLogOn~&cKey=87&uType=RTS

Waste Management Program

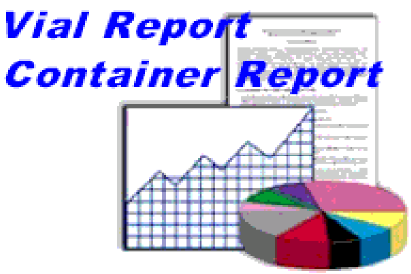
McGill

Tel: 514-398-5066 Fax: 514-398-4633
www.mcgill.ca/wmp

Radioisotope Tracking System

Licence Holder	Licence Holder Inventory		
	Radioisotope Vials	In Progress	Waste Containers
Licence #: 5-0038-03 ROYAL VICTORIA HOSPITAL MS MAUREEN MCQUEEN RADIATION PROTECTION 842-1231 EXT 36133	RTS-15003 P-32		

New Vial in list



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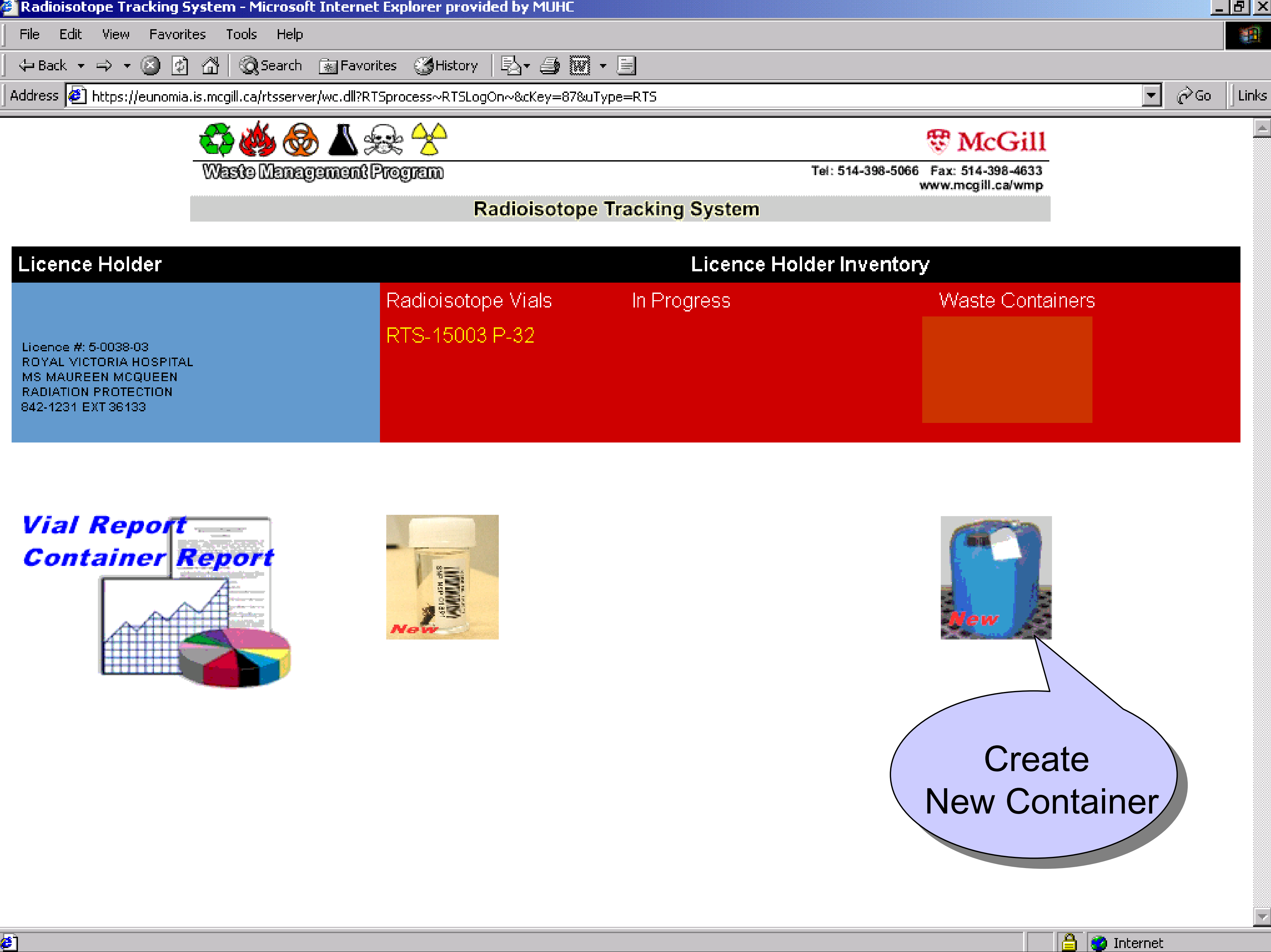
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Radioisotope Tracking System
Licence Holder
Licence Holder Inventory
Radioisotope Vials
In Progress
Waste Containers
RTS-15003 P-32
Licence #: 5-0038-03
ROYAL VICTORIA HOSPITAL
MS MAUREEN MCQUEEN
RADIATION PROTECTION
842-1231 EXT 36133
Vial Report
Container Report
New
New
Create New Container
Internet

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ess https://eunomia.is.mcgill.ca/rtsserver/wc.dll?rtsprocess~NewContainer Go

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Radioisotope Tracking System

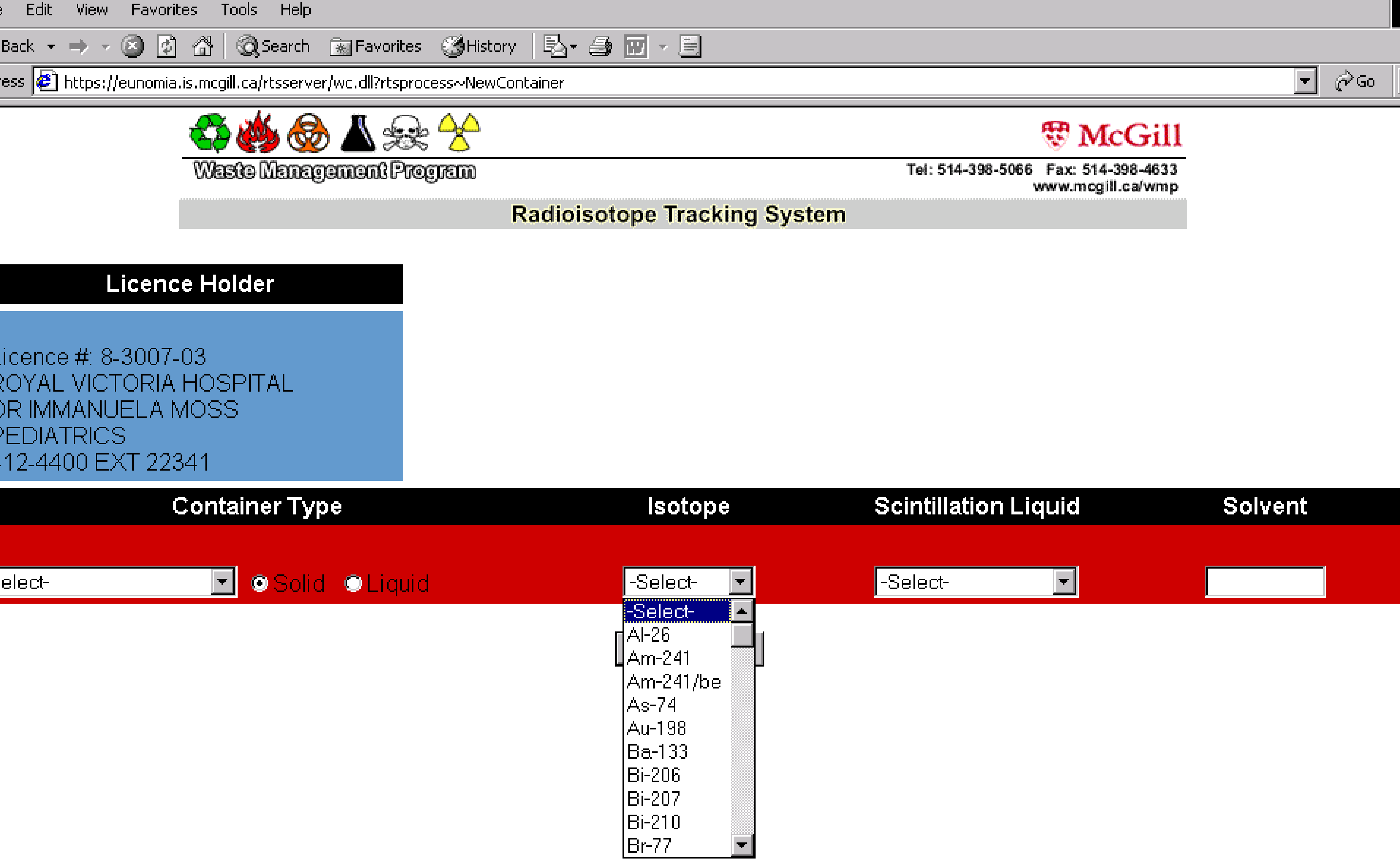
Licence Holder

icence #: 8-3007-03
ROYAL VICTORIA HOSPITAL
DR IMMANUELA MOSS
PEDIATRICS
12-4400 EXT 22341

Container Type	Isotope	Scintillation Liquid	Solvent
elect- ◉ Solid ○ Liquid	-Select-	-Select-	

elect-
PLASTIC CONTAINER
L CARDBOARD BOX
L STEEL PAIL
PLASTIC CONTAINER

Save Reset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Back Search Favorites History
https://eunomia.is.mcgill.ca/rtsserver/wc.dll?rtsprocess~NewContainer
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Waste Management Program
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Radioisotope Tracking System
Licence Holder
icence #: 8-3007-03
ROYAL VICTORIA HOSPITAL
DR IMMANUELA MOSS
PEDIATRICS
12-4400 EXT 22341
Container Type
Isotope
Scintillation Liquid
Solvent
elect-
Solid
Liquid
-Select-
-Select-
-Select-
Al-26
Am-241
Am-241/be
As-74
Au-198
Ba-133
Bi-206
Bi-207
Bi-210
Br-77

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ess https://eunomia.is.mcgill.ca/rtsserver/wc.dll?rtsprocess~NewContainer Go

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Radioisotope Tracking System

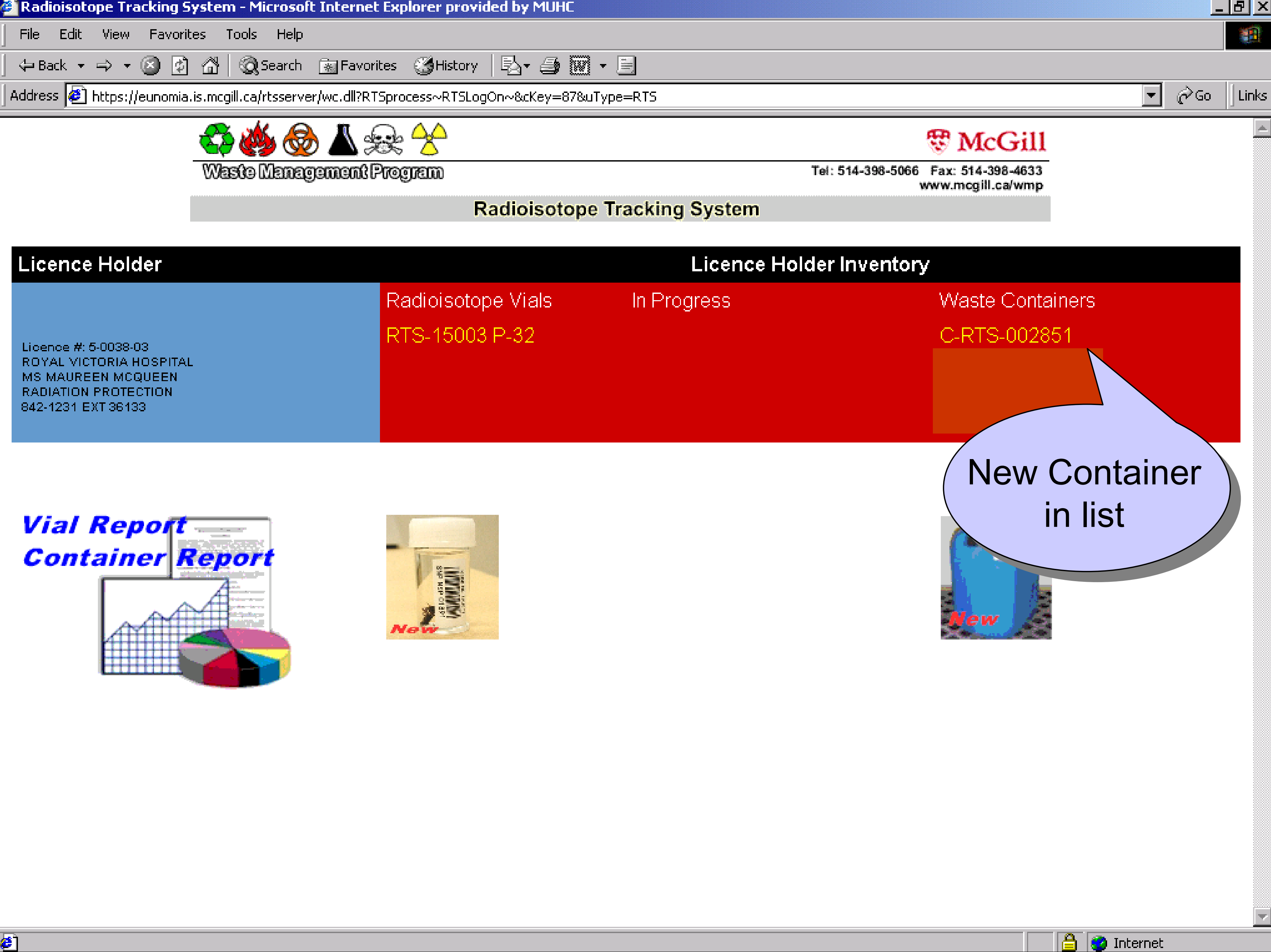
Licence Holder

icence #: 8-3007-03
ROYAL VICTORIA HOSPITAL
DR IMMANUELA MOSS
PEDIATRICS
12-4400 EXT 22341

Container Type	Isotope	Scintillation Liquid	Solvent
elect- ◉ Solid ○ Liquid	-Select-	-Select-	

-Select-
BIODEGRADABLE
ORGANIC

Save Reset


Radioisotope Tracking System - Microsoft Internet Explorer provided by MUHC
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Address https://eunomia.is.mcgill.ca/rtsserver/wc.dll?RTSprocess~RTSLogOn~&cKey=87&uType=RTS
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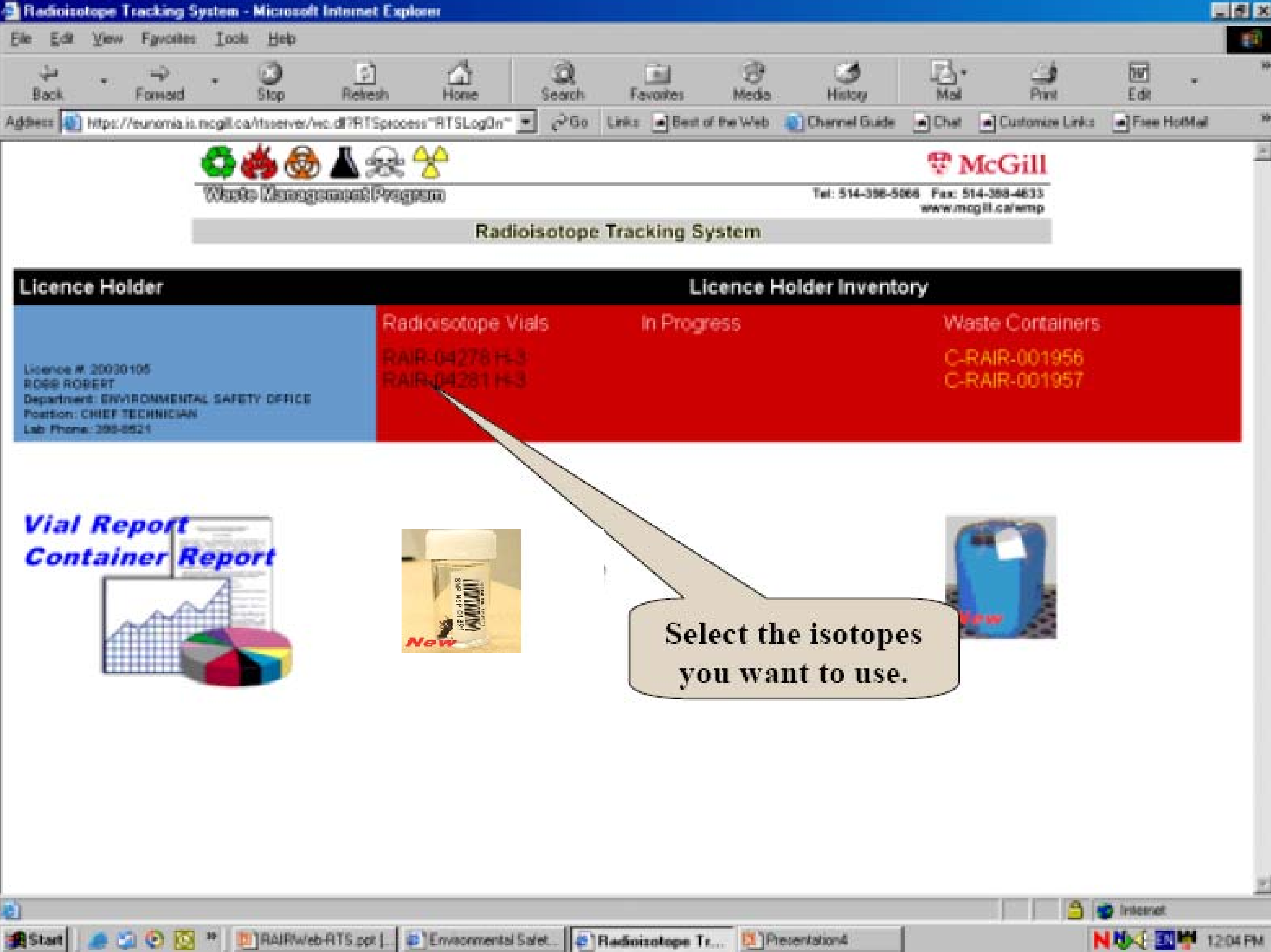
Radioisotope Tracking System
Licence Holder
Licence Holder Inventory
Radioisotope Vials
In Progress
Waste Containers
RTS-15003 P-32
C-RTS-002851
Licence #: 5-0038-03
ROYAL VICTORIA HOSPITAL
MS MAUREEN MCQUEEN
RADIATION PROTECTION
842-1231 EXT 36133
New Container in list
Vial Report
Container Report
New
New
Internet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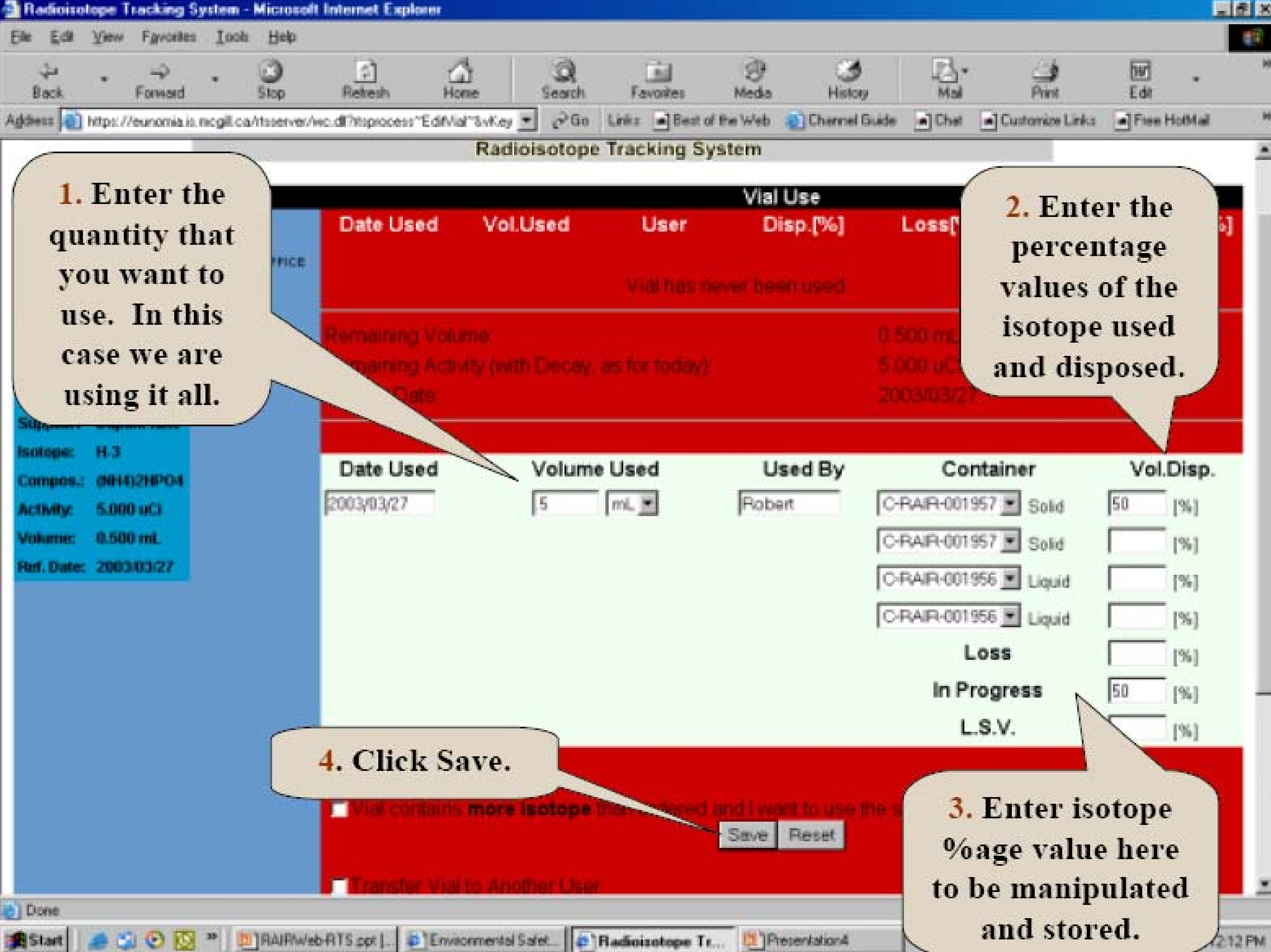
Radioisotope Tracking System
Licence Holder
Licence Holder Inventory
Radioisotope Vials
In Progress
Waste Containers
Licence #: 20030105
ROBB ROBERT
Department: ENVIRONMENTAL SAFETY OFFICE
Position: CHIEF TECHNICIAN
Lab Phone: 398-8521
RAIR-04276 H-3
RAIR-04281 H-3
C-RAIR-001956
C-RAIR-001957
Vial Report
Container Report
New
New
Select the isotopes you want to use.


Radioisotope Tracking System - Microsoft Internet Explorer
File Edit View Favorites Tools Help
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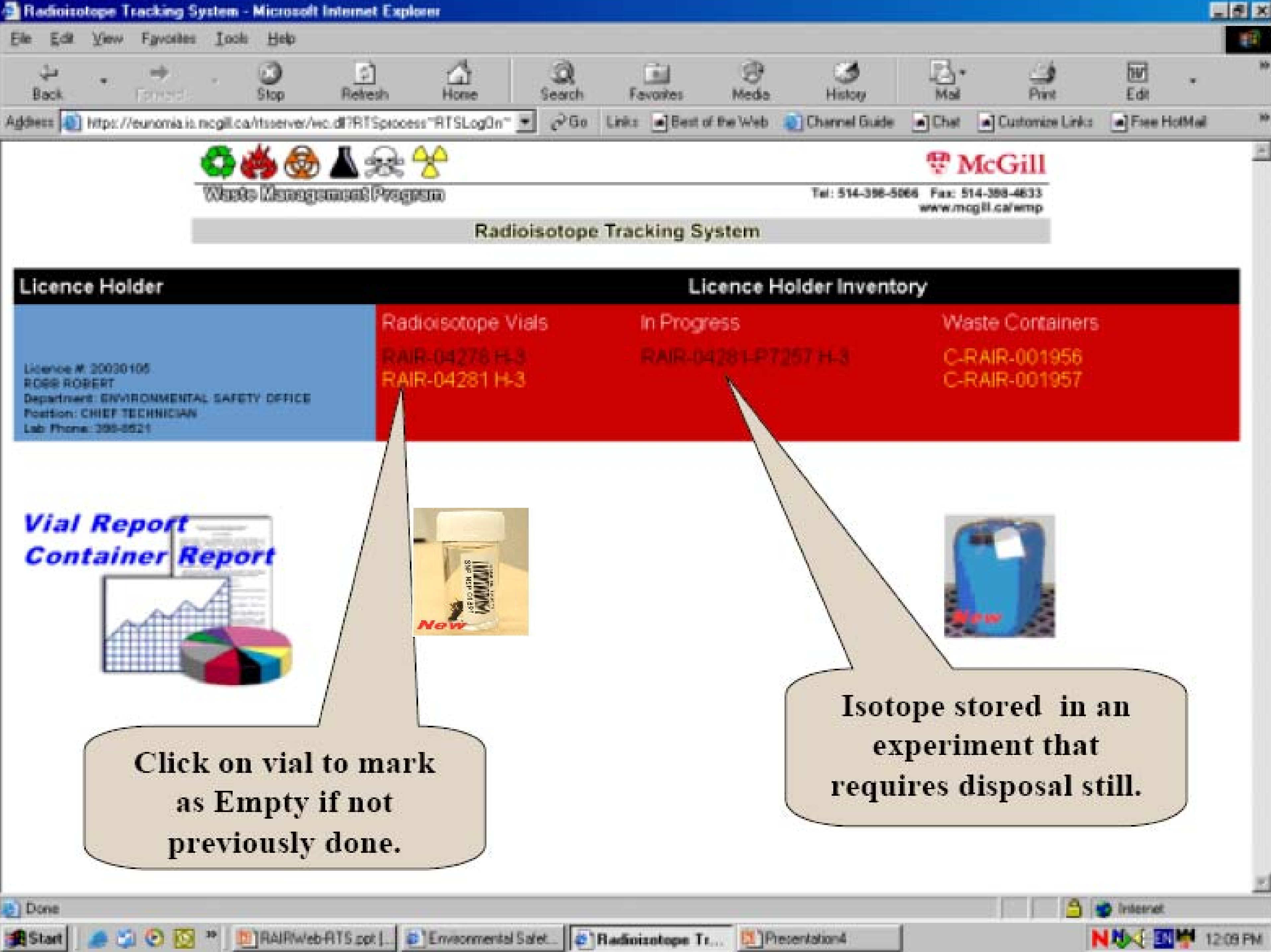
Address https://eunomia.is.mcgill.ca/rtsserver/wc.dll?rtsprocess~EditVial~&vKey
Go Links Best of the Web Channel Guide Chat Customize Links Free HotMail
Radioisotope Tracking System
1. Enter the quantity that you want to use. In this case we are using it all.
Vial Use
Date Used Vol.Used User Disp.[%] Loss[
2. Enter the percentage values of the isotope used and disposed.
Vial has never been used
Remaining Volume: 0.500 mL
Remaining Activity (with Decay, as for today): 5.000 uC
2003/03/27
Isotope: H-3
Compos.: (NH4)2HPO4
Activity: 5.000 uCi
Volume: 0.500 mL
Ref. Date: 2003/03/27
Date Used Volume Used Used By Container Vol.Disp.
2003/03/27 5 mL Robert C-RAIR-001957 Solid 50 [%]
C-RAIR-001957 Solid [%]
C-RAIR-001956 Liquid [%]
C-RAIR-001956 Liquid [%]
Loss [%]
In Progress 50 [%]
L.S.V. [%]
4. Click Save.
Vial contains more isotope
Save Reset
Transfer Vial to Another User
3. Enter isotope %age value here to be manipulated and stored.
Done
Start RAIRWeb-RTS.ppt Environmental Safet... Radioisotope Tr... Presentation4



Radioisotope Tracking System - Microsoft Internet Explorer
Radioisotope Tracking System
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Waste Management Program
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Licence Holder
Licence Holder Inventory
Licence #: 20030106
ROBB ROBERT
Department: ENVIRONMENTAL SAFETY OFFICE
Position: CHIEF TECHNICIAN
Radioisotope Vials
RAIR-04278 H-3
RAIR-04281 H-3
In Progress
RAIR-04281-P7257 H-3
Waste Containers
C-RAIR-001956
C-RAIR-001957
Vial Report
Container Report
New
New
Click on vial to mark as Empty if not previously done.
Isotope stored in an experiment that requires disposal still.

Radioisotope Tracking System - Microsoft Internet Explorer

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Address http://erato.is.mcgill.ca/rtsserver/wc.dll?RTSprocess~PrintVialReport Go

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Radioisotope Tracking System

Vial Report by Vial Number ordered by Vial Number

Vial #	Isotope	Ref. Date	Rcvd. Date	Vol.Init[mL]	Activ.Init	Vol.Curr.[mL]	Act.Curr. [uCi]	Empty
RTS-00001	Cr-51	2002/03/18	2002/03/20	50.000	100.000	50.000	37.825	No

Vial #	Isotope	Ref. Date	Rcvd. Date	Vol.Init[mL]	Activ.Init	Vol.Curr.[mL]	Act.Curr. [uCi]	Empty
RTS-00002	P-33	2002/03/15	2002/03/20	60.000	100.000	20.000	8.520	No

Date Use	Vol Used	User	Disposed[%]	Loss[%]	Progress[%]
2002/03/23	30.000 mL	CRIS	100.00	0.00	0.00
2002/03/25	10.000 mL	CRIS	100.00	0.00	0.00

Vial #	Isotope	Ref. Date	Rcvd. Date	Vol.Init[mL]	Activ.Init	Vol.Curr.[mL]	Act.Curr. [uCi]	Empty
RTS-00017	Bi-210	2002/04/26	2002/04/26	45.000	200.000	45.000	-9.000	No

TOTAL ACTIVITY IN = 400.000 uCi TOTAL VOLUME IN = 155.000 mL
TOTAL ACTIVITY LEFT = 37.345 uCi TOTAL VOLUME LEFT = 115.000 mL

Done Internet

Radioisotope Tracking System - Microsoft Internet Explorer provided by MUHC

File Edit View Favorites Tools Help

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www.mcgill.ca/wmp

Radioisotope Tracking System

Licence Holder	Licence Holder Inventory		
	Radioisotope Vials	In Progress	Waste Containers
Licence #: 8-3007-03 ROYAL VICTORIA HOSPITAL DR IMMANUELA MOSS PEDIATRICS 412-4400 EXT 22341			C-RTS-001985 C-RTS-001986 C-RTS-005105

Container report

Vial Report
Container Report

http://www.mcgill.ca/wmp/ Internet

Radioisotope Tracking System - Microsoft Internet Explorer provided by MUHC

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Address https://eunomia.is.mcgill.ca/rtsserver/wc.dll?rtsprocess~EditCont~&kKey=1985&cKey=51&uType=RTS Go Links

Waste Management Program

McGill

Tel: 514-398-5066 Fax: 514-398-4633
www.mcgill.ca/wmp

Radioisotope Tracking System

Licence Holder	Container Use				
Licence #: 8-3007-03 ROYAL VICTORIA HOSPITAL DR IMMANUELA MOSS PEDIATRICS 412-4400 EXT 22341	**Date Used**	**Activ. Used**	**In History**	**Vial No.**	**User**
	2003/04/01	7.511	0.000	RTS-04002	A LAFERRIERE
	2003/04/01	7.511	7.511	RTS-04003	A LAFERRIERE
	2003/12/08	11.563	0.811	RTS-09184	A LAFERRIERE
	2004/05/07	13.462	2.138	RTS-12211	A LAFERRIERE

Container No.	C-RTS-001985
Isotope	I-125
Cont. Type	4L PLASTIC CONTAINER
Form	Liquid
Scint. Liquid	
Solvent	
Entered	2003/03/29
Last Used	2003/03/29

Total Activity (without decay) = 40.047

Activity to Date (with Decay) = 2.428

Click when Container is Full to Obtain Label Information

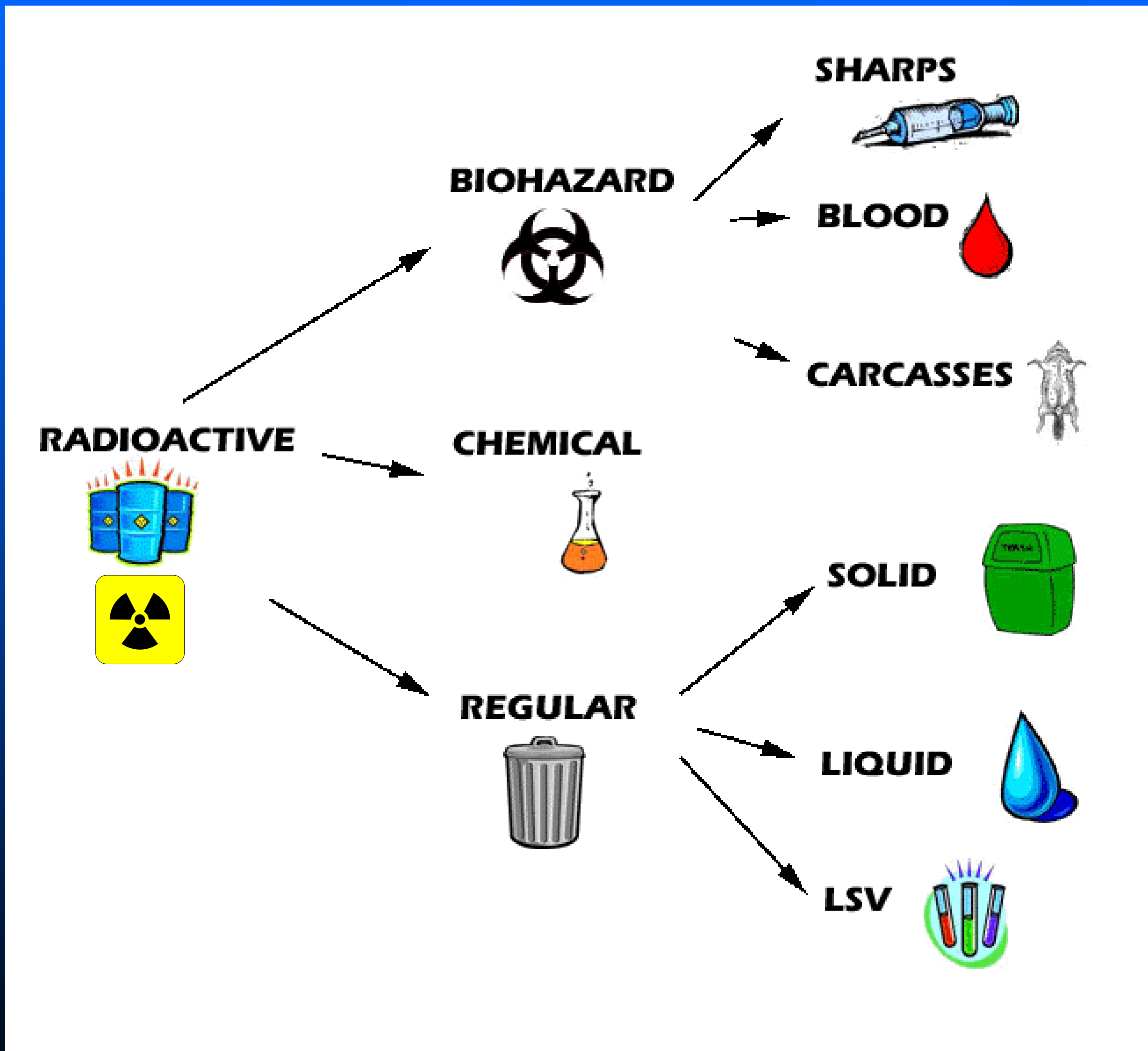
Done Internet

Waste Management

Radioactive Waste Disposal

- Segregate waste by form (solid, liquid) and isotope
- A running total amount of activity and isotope in waste must be kept on container – replace as required
- Label waste as well as record in RTS inventory

Waste Disposal Guidelines



Regular Radioactive Waste

4 L white plastic container
1 L clear plastic container

Both used for liquid or for solids (no mixing of solids & liquids).

Metal pail (20 litre) used for solid and for liquid scintillation vials (LSVs).

Cardboard box (20 litre) used for solid waste

Mixed Biomedical & Radioactive Waste

Disposal of biomedical waste is governed by the Regulation Respecting Biomedical Waste (Québec), and encompasses the following categories:

- human anatomical waste (body parts or organs),
- animal anatomical waste (carcasses, body parts, organs),
- non-anatomical waste, which includes:
- sharps which have contacted animal or human blood, biological fluids or tissues
- tissue or microbial cultures, and material contaminated by such cultures
- live vaccines
- containers or materials saturated with blood products.

Mixed Biomedical & Radioactive Waste

For biohazard waste that are radioactive, always use biohazard waste route and write

R/A

in red on the box (as per McGill Waste Management instructions)

LSV Waste Tag

1. Isotope / Isotopes
2. Activity
3. Date *measured*
4. # Permit
5. Initials

Lead/Plastic Pigs

Lead pigs are recyclable.

-**Must be tested** for contamination.

Plastic pigs are not recyclable

-may be presented as garbage
-**must be free** of contamination and radioactive markings.

Code brown: Internal spill or release of hazardous materials

Call 55555
Department responsible: Occupational Health and Safety (OH&S)

Definition:

Code brown is used to alert MUHC personnel of an internal hazardous spill of chemical and pharmaceutical products, radioisotopes and biohazardous materials, as well as gas leak

In the event of a chemical spill, the individual(s) who caused the spill or the first individual who noticed the spill or leak is responsible for prompt and proper communication with other occupants, his/her immediate supervisor, and locating.

Spill Procedure

- MINOR SPILLS (< 100 EQ)
  - Inform persons in immediate area, limit access
  - Cover spill with absorbent material
  - Clean up spill using absorbent paper and place in plastic bags
  - Wipe test or survey for residual contamination as appropriate.
  - Repeat until decontamination criteria is exceeded
  - Check hands, clothing and shoes for contamination
  - Package and label clean up materials for disposal.
  - Record spill details and contamination monitoring (wipe tests) results.
  - Adjust inventory and waste records as appropriate

Assess Contamination
(isotope, activity) Minor or major ?

Clean up using absorbent pads

Survey, identify region

repeat cleaning + wipe tests as necessary

Spill Procedure

- MAJOR SPILLS (> 100 EQ)
  - Clear the area
  - Leave fume hood running (if available)
  - Close off area and post warning signs
  - Notify RPS
  - Decontaminate personnel by removing clothing and flushing skin with warm water and soap
  - Follow procedure for minor spill
  - Record names of person involved in spill
  - Submit written report to RPS
  - RPS will submit report to CNSC

Appendix I

Two Important Calculations

CALCULATIONS

TWO IMPORTANT CALCULATION:

1. Wipe test contamination level

2. Decay correction

Wipe Test Contamination Level

$$CL(Bq/cm^2) = \frac{N(CPM) - Bkg(CPM)}{CE \times 60 \times A \times Weff}$$

CL	=	*Contamination Level in Bq/cm²*
N	=	*Total counts in CPM*
Bkg	=	*Background counts in CPM*
CE	=	*Detector efficiency (0-1)*
60	=	*sec/min*
A	=	*Area wiped (100 cm2)*
Weff	=	*Wipe efficiency (0.1 wet ; 0.01 dry)*

Wipe Test Contamination Level

EXAMPLE :

N	=	*500 CPM*	*(Total counts)*
Bkg	=	*300 CPM*	*(Bkg counts)*
CE	=	*0.6*	*(Det efficiency)*
A	=	*100 cm2*	*(Area wiped)*
Weff	=	*0.1*	*(Wipe efficiency)*

$$CL = \frac{500 - 300}{0.6 \times 60 \times 100 \times 0.1} = 0.55 Bq / cm^2$$

Decay Correction

$$A_f = \frac{A_0}{2^N} \quad ; \quad N = t / T_{1/2}$$

A_0 = *Initial activity*
A_f = *final activity*
t = *time elapsed*
$T_{1/2}$ = *half-life*

Note:

$$A_f = A_0 \exp(-\ln(2^N))$$
$$= A_0 \exp(-N \times \ln(2))$$
$$= A_0 \exp(-0.693 \times t / T_{1/2})$$

$$A_f = A_0 \exp(-\lambda t) \quad (\lambda = 0.693 / T_{1/2})$$

Decay Correction

Example:

- 250 μCi of ^{35}S arrived on May 19, 2002
- 100 μCi was removed and used the same day.
- The remaining amount was stored in a freezer for future use.
- On June 30, 2002 it is decided to repeat the experiment.

Q :Does another order of ^{35}S have to be placed or is there enough remaining activity that the experiment may proceed?

Decay Correction

Solution: $$A_f = A_o \exp(-\lambda t)$$

A_f = activity at time "t" (?)

A_0 = activity at time zero (250 - 100 = 150 μCi)

t = elapsed time (42 d)

λ = decay constant (0.693 / 87.44 d = 0.0079)

$$A_f = 150 \exp(- 0.0079 \times 42)$$

$$= 107.52 \ \mu Ci$$

** SAVINGS **

Le centre universitaire de santé McGill (CUSM)
McGill University Health Center (MUHC)

Service de radioprotection
Radiation Protection Service

Ceci certifie que :
This is to certify that :

A réussi avec succès la formation du CUSM en radioprotection à l'intention des travailleurs du secteur des radioisotopes.
Has successfully completed the MUHC radiation Safety Training for Radioisotope Workers

Date of training:

RSO's signature:

Service de la radioprotection
Radiation Protection Service

MUHC Radiation Protection Service

- Christian Janicki RSO and manager x 43866
- Malika Oussaid, RS Assistant x 36484
- Mohammed Lounis, RS Assistant x 44922

- 24h pager through Locating x 53333