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# Production and Decay of Radioisotopes

A resource for NSW HSC Chemistry and Physics Teachers and Students

November 2011

# Production and Decay of Radioisotopes

This document covers a number of outcomes from the HSC Chemistry Syllabus and HSC Physics Syllabus.

## HSC Chemistry

### 9.2 Production of Materials: 5. Nuclear materials

- describe how transuranic elements are produced
- describe how commercial radioisotopes are produced
- Identify one use of a named radioisotope:
  - in industry
  - in medicine
- describe the way in which the above named radioisotopes are used and explain their use in terms of their properties
- use available evidence to analyse benefits and problems associated with the use of radioactive isotopes in identified industries and medicine

## HSC Physics

### 9.6 Option – Medical Physics: 3. Radioactivity as a diagnostic tool

- outline properties of radioactive isotopes and their half lives that are used to obtain scans of organs
- describe how radioactive isotopes may be metabolised by the body to bind or accumulate in the target organ
- identify that during decay of specific radioactive nuclei positrons are given off
- discuss the interaction of electrons and positrons resulting in the production of gamma rays
- describe how the positron emission tomography (PET) technique is used for diagnosis

### 9.8 Option – From Quanta to Quarks: 4. Applications of a knowledge of the structure of the atom

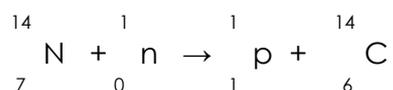
- describe some medical and industrial applications of radioisotopes
- identify data sources, and gather, process, and analyse information to describe the use of
  - a named isotope in medicine
  - a named isotope in agriculture
  - a named isotope in engineering

## Summary of equations

### A. Neutron rich radioisotopes

#### a) Pure $\beta^-$ emitter: C-14

Production – natural process initiated by cosmic rays in upper atmosphere (and is therefore called a 'cosmogenic radioisotope').

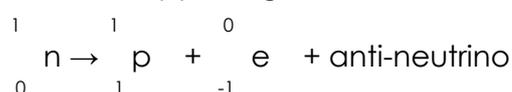


Decay – half-life ( $t_{1/2}$ ) = 5730 years



This is a pure  $\beta^-$  emitter, in other words, there is no emission of  $\gamma$ .

What is happening in the nucleus?



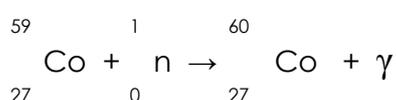
The anti-neutrino arises from the change in spin of one of the quarks making up the neutron and proton (neutron spins = udd; proton spins = uud).

C-14 is present in all living things. Radiocarbon dating is based on the proportion of C-14:C-12 present in a sample from the remains of something that was once living. The absolute upper limit of reliability of radiocarbon dating is 50 000 years. If a sample tests as 50 000+ years, scientists must use another longer-lived radioisotope to more accurately determine the age of the sample.

At ANSTO, our ANTARES and STAR linear accelerators are used to carry out radiocarbon dating of samples.

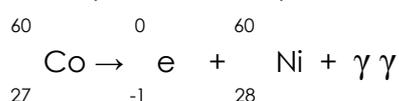
#### b) $\beta^-$ and $\gamma$ emitter: Co-60

Production – artificial radioisotope produced in a nuclear reactor:



The  $\gamma$  produced in this reaction is called a **prompt  $\gamma$** . These are always produced with neutron absorption into a nucleus.

Decay –  $t_{1/2} = 5.27$  years



At ANSTO we use Co-60 in a facility called GATRI for the following purposes:

i) To set the standards for sterilisation of medical supplies in Australia for example, syringes/bandages/plasters

ii) Three hospitals in Australia (Brisbane, Sydney, Perth) operate human bone and tendon banks. Bones and tendons are stored in an esky with dry ice and sent here. They are irradiated so that no live matter can survive –DNA is killed off. This means that a patient's immune system will not reject it as there is no foreign DNA (therefore immunosuppressant drugs not required) and there will be no infection present.

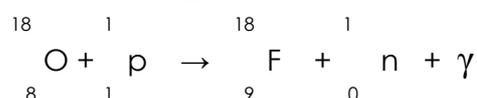
iii) The Queensland Fruit Fly is a pest which can cause massive damage to fruit crops. In southern NSW, northern Vic and South Australia there are areas called 'fruit fly exclusion zones'. In these areas there are insect traps and if two Queensland fruit flies are found in a trap this constitutes an 'outbreak'. When that occurs, the Macarthur Agricultural Institute near Camden, NSW, breeds the fruit fly to the pupae stage. Cartons containing 6.4 million pupae are irradiated in GATRI, not to kill them but to make them sterile. They are released in the exclusion zone and mate but do not produce any offspring. This process is repeated over a ten week period – a total of 64 million fruit fly are released!

## B. Neutron deficient radioisotopes

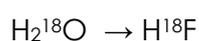
These can decay in a number of ways but only positron emission will be covered here.

Fluorine-18.

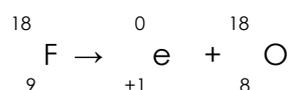
Production – artificial radioisotope produced in a cyclotron and used in medical diagnostic scans called Positron Emission Tomography (PET) scans.



The target is water, H<sub>2</sub>O, enriched with the O-18 isotope. In summary:

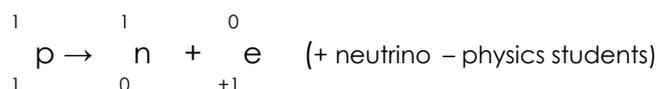


The F-18 decays by the emission of a positron to form O-18:

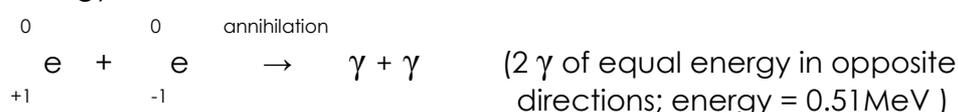


Note: no  $\gamma$  is emitted with the emission of the positron.

What is happening in the nucleus?



The positron then travels a short distance, losing energy until it is at the correct energy to meet and combine with a free electron. Annihilation then occurs:

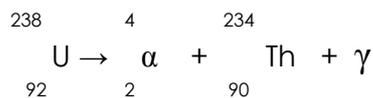
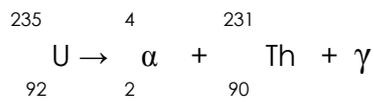


The 2  $\gamma$  rays emitted are called a coincident pair.

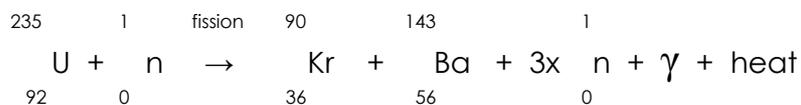
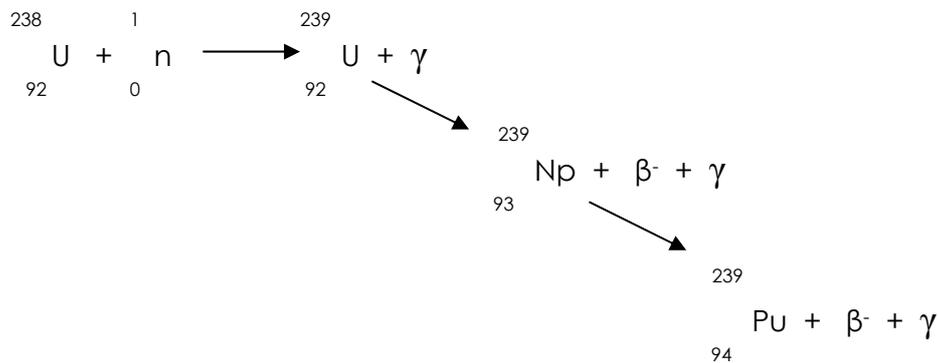
The F-18 is attached to a pharmaceutical to form the radiopharmaceutical FDG, fluoro-deoxyglucose. The body sees the FDG as glucose and when administered to a patient, the FDG will travel to parts of the body requiring energy. Areas such as active tumours require energy and therefore the FDG accumulates in the tumour. The PET detectors are arranged in a ring through which the patient is moved. The coincident pairs of  $\gamma$  rays given off in the annihilation are detected and images are produced in slices. These can then be combined to give a 3-dimensional picture.

### C. Decay of large nuclei

Natural  $\alpha$  decay of uranium isotopes



The behaviour of U-238 and U-235 differs when bombarded by neutrons:



U-238 does not undergo fission whereas U-235 does. U-238 does however lead to the formation of Pu-239 which will undergo fission. U-238 is called FERTILE whereas U-235 and Pu-239 are called FISSILE.

### D. Medical Radioisotopes

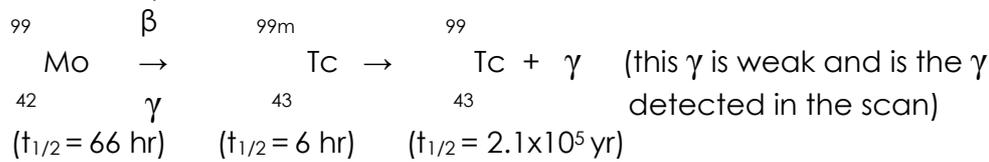
#### a) Molybdenum-99

Production – a target containing uranium is irradiated in a nuclear reactor. Many different fission reactions are possible but one produces Mo-99:



Approximately 6% of the fission fragments are Mo-99.

Decay – Mo-99 decays to the most widely used medical diagnostic radioisotope in the world, Tc-99m:



Tc-99m is not produced directly as it has a relatively short half life (6 hours). It is more practical to produce Mo-99 ( $t_{1/2} = 66$  hours) and dispatch it in suitably shielded transport containers called GenTech Generators. When the Generator reaches its destination, the Tc-99m can be extracted from the Generator in a process called 'elution'.

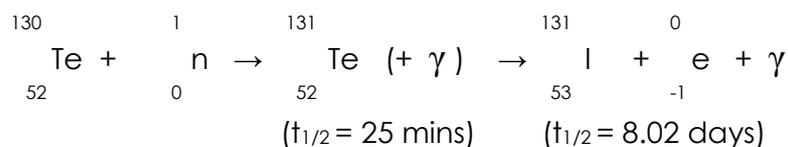
Tc-99m can be used to show the presence of tumours/cancers and to determine how an organ is functioning. Some of the parts of the body that can be examined include: brain, heart, kidneys, bones, bone marrow, stomach, thyroid glands, lungs, blood pool and flow, salivary glands, lacrimal glands (+ lots of others).

Interesting facts about Mo-99 and Tc-99m:

- In mid 2009 ANSTO was granted a licence for the production of Mo-99 for export markets
- 1 dose of Tc-99m = 50 – 100 pg (1 pg =  $10^{-12}$  g)
- Doses in a GenTech = ~50 doses
- Doses can be extracted from a GenTech generator for ~1 week

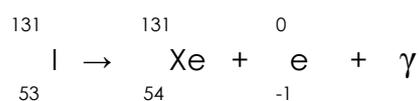
## b) Iodine-131

Production – a target of TeO<sub>2</sub> enriched with Te-130 is irradiated in a nuclear reactor:



The iodine-131 can be used in the form of sodium iodide (NaI) or can also be attached to a pharmaceutical to form meta-iodobenzylguanidine (MIBG).

Decay



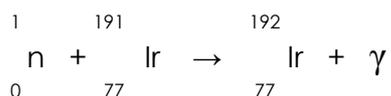
The negative beta particles are very high energy and attack the cells of the cancer tumour. After administration of the I-131 radiopharmaceutical, the patient becomes a radioactive source and therefore must be kept in isolation

due to possible contamination. In addition the patient must not come into contact with pregnant women or young children as the gamma emissions could cause developmental damage to foetuses or growing children.

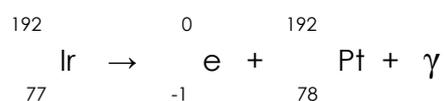
## E) Industrial Radioisotope

### a) Iridium-192

Production – Ir-191 is irradiated in a nuclear reactor:

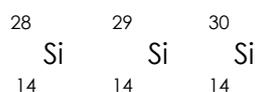


Decay – the  $\gamma$  produced can be used in industrial detection processes (e.g. finding flaws in metals)

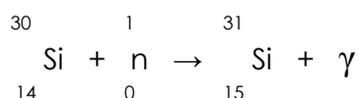


### b) Irradiation of Silicon – Doping

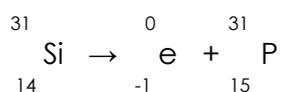
The starting material is a high purity silicon block containing 3 naturally occurring and stable isotopes of silicon:



When Si-30 absorbs a neutron it produces radioactive Si-31 ( $t_{1/2}=2.6$  hours):



The Si-31 decays to produce P-31:



Once the silicon blocks have been irradiated they are changed into a semiconductor suitable for making silicon chips in computers, mobiles and other electronic devices.

## Production of transuranics in a linear accelerator

U-238 can be bombarded with smaller nuclei in an accelerator:

