GET1024 / GEC1036
Radiation – Scientific Understanding and Public Perception
Tutorial 5

The questions in this tutorial session were taken from past years' term tests on topics not covered in tutorials so far. They are also given to help you prepare for Term Test 2 on Week 13. The tutor will cover the ones that many of you may have difficulties and those which are more interesting.

Future Nuclear Power Plants

(1) Which of the following reactors is not considered to be a Gen IV reactors?

- A) Light Water Small Modular Reactor (SMR)
- B) Molten Salt Reactor (MSR)
- C) Sodium-Cooled Fast Reactor (SFR)
- D) Supercritical Water-Cooled Reactor (SCWR)
- E) Gas-Cooled Fast Reactor (GFR)

(2) Generation III/III+ reactors are evolutionary improvements over Generation II reactors. Which of the following is not one of the intended improvements?

- A) Lower core damage frequency (CDF) √
- B) Longer operational life of plant √
- C) Significantly enhanced safety systems √
- D) Higher performance, e.g., in fuel efficiency and longer refueling cycle √
- E) More optimum use of uranium-238 X

(3) Which of the following is NOT an advantage of small modular reactor (SMR)?

- A) Due to the smaller power in each reactor, passive safety system may be used to remove decay heat efficiently to reduce the chance of core melt.
- B) The initial cost of construction of NPP is much lower and thus is more attractive to investors.
- C) Reactors can be connected together or added according to demand.
- D) SMR may be used in remote areas which requires lower power.
- E) The cost per unit energy produced is lower than the traditional N

(4) What of the following are some of the challenges to realising commercial fusion reactors?

- (I) Negligible amount of natural tritium √
- (II) Extreme conditions, e.g., temperature, needed √
- (III) Extremely toxic nature of tritium and its long half-life X
- (IV) Lack of any means of producing large amount of deuterium needed for fusion √

A) (I) and (II) only
B) (II) and (III) only
C) (III) and (IV) only
D) (I), (II) and (III) only
E) (I), (II), (III) and (IV)

Questions 5 – 7 are based on Article 2 on *GIF Reactor Technologies.* Read the passage before answering the questions.

(5) Which of the reactors are expected to operate at the highest temperature and highest pressure?

	Highest Temperature	Highest Pressure
A)	SCWR	SCWR
B)	VHTR	GFR
C)	MSR	VHTR
D)	MSR	SCWR
E)	VHTR	SCWR

(6) According to the passage, which of GIF reactor technologies were based on actual reactors that have been operated in the past or are currently still being operated?
A) SFR, LFR and GFR
B) MSR, SCWR and VHTR
C) SFR, LFR and VHTR
D) SCWR, SFR and VHTR
E) LFR, MSR and SCWR

(7) Based on the information given in the passage and your understanding of closed and open fuel cycle, which of the statements below is **TRUE**?
A) The aim for all GIF reactors is to achieve closed fuel cycle.
B) There is no reactor that can operate on either open or closed fuel cycle.
C) SFR, LFR and GFR operate on closed fuel cycle.
D) SCWR and VHTR operate on closed fuel cycle.
E) All the GIF reactors are expected to operate on open fuel cycle.

GIF Reactor Technologies

Gas-cooled fast reactors (GFR)

Like other helium-cooled reactors which have operated or are under development, these will be high-temperature units – 850°C, suitable for power generation, thermochemical hydrogen production or other process heat. For electricity, the gas will directly drive a gas turbine (Brayton cycle). Fuels would include depleted uranium and any other fissile or fertile materials. Spent fuel would be reprocessed on site and all the actinides recycled to minimise production of long-lived radioactive wastes. While General Atomics worked on the design in the 1970s (but not as fast reactor), none has so far been built.

Lead-cooled fast reactors (LFR)

Liquid metal (Pb or Pb-Bi) cooling is by natural convection. Fuel is depleted uranium metal or nitride, with full actinide recycle from regional or central reprocessing plants. A wide range of unit sizes is envisaged, from factory-built "battery" with 15 – 20 year life for small grids or developing countries, to modular 300 – 400 MWe units and large single plants of 1400 MWe. Operating temperature of 550°C is readily achievable but 800°C is envisaged with advanced materials and this would enable thermochemical hydrogen production.

This corresponds with Russia's BREST fast reactor technology which is lead-cooled and builds on 40 years' experience of lead-bismuth cooling in submarine reactors. Its fuel is U+Pu nitride. More immediately the GIF proposal appears to arise from two experimental designs: the US STAR and Japan's LSPR, these being lead and lead-bismuth cooled respectively.

Molten salt reactors (MSR)

The uranium fuel is dissolved in the sodium fluoride salt coolant which circulates through graphite core channels to achieve some moderation and an epithermal neutron spectrum. Fission products are removed continuously and the actinides are fully recycled, while plutonium and other actinides can be added along with U-238. Coolant temperature is 700°C at very low pressure, with 800°C envisaged. A secondary coolant system is used for electricity generation, and thermochemical hydrogen production is also feasible.

Sodium-cooled fast reactors (SFR)

This builds on more than 300 reactor-years experienced with fast neutron reactors over five decades and in eight countries. It utilises depleted uranium in the fuel and has a coolant temperature of 550°C enabling electricity generation via a secondary sodium circuit, the primary one being at near atmospheric pressure. Two variants are proposed: a 150 – 500 MWe type with actinides incorporated into a metal fuel requiring pyrometallurgical processing on site, and a 500 – 1500 MWe type with conventional MOX fuel reprocessed in conventional facilities elsewhere.

Early in 2008, the USA, France and Japan signed an agreement to expand their cooperation on the development of sodium-cooled fast reactor technology. The agreement relates to their collaboration in the Global Nuclear Energy Partnership, aimed at closing the nuclear fuel cycle through the use of advanced reprocessing and fast reactor technologies, and seeks to avoid duplication of effort.

Supercritical water-cooled reactors (SCWR)

This is a very high-pressure water-cooled reactor which operates above the thermodynamic critical point of water to give a thermal efficiency about one third higher than today's light water reactors from which the design evolves. The supercritical water (25 MPa and 510 – 550°C) directly drives the turbine, without any secondary steam system. Passive safety features are similar to those of simplified boiling water reactors. Fuel is uranium oxide, enriched in the case of the open fuel cycle option. However, it can be built as a fast reactor with full actinide recycle based on conventional reprocessing. Most research on the design has been in Japan.

Very high-temperature gas reactors (VHTR)

These are graphite-moderated, helium-cooled reactors, based on substantial experience. The core can be built of prismatic blocks such as the Japanese HTTR and the GTMHR under development by General Atomics and others in Russia, or it may be pebble bed such as the Chinese HTR-10 and the PBMR under development in South Africa, with international partners. Outlet temperature of 1000°C enables thermochemical hydrogen production via an intermediate heat exchanger, with electricity cogeneration, or direct high-efficiency driving of a gas turbine (Brayton cycle). There is some flexibility in fuels, but no recycle. Modules of 600 MW thermal are envisaged.

Nuclear Fuel Cycle & Nuclear Wastes

(1) Which of the following statements on different methods of uranium mining is / are true?

(I) Underground mining results in higher amount of waste rocks than open pit mining. ?

(II) Health risk due to radon is highest using underground mining compared to other forms of mining methods. ✓

(III) In-situ mining may result in the contamination of aquafers. ✓

(IV) Open pit mining is the least expensive method to mine for uranium. ✓

A) (II) only ✗
B) (I) and (III) only ✗
C) (I) and (IV) only ✗
D) (I), (II) and (IV) only ✗
E) (II), (III) and (IV) only

(2) Uranium ores are mined and later milled to produce yellow cake with high concentration of uranium. The mill tailings left behind by this process present hazards to residents around the region. Which of the following is not a possible cause for concern?

A) Higher release of gaseous radon-222 to the atmosphere and subsequent inhalation. ✓
B) Higher level of radioactive iodine-131 from the fission of uranium left behind in the tailings. ✓ ?
C) Possible dust loading of contaminants containing radium, arsenic, etc. due to natural wind conditions. ✓
D) Higher level of direct gamma radiation exposure from the tailings. ?
E) Possible groundwater seepage and subsequent contamination of local aquifers which potentially could affect the water supply. ✓

This is gaseous diffusion

(3) The main principle of enriching uranium through the gas centrifuge is that

A) the heavier gas molecules tend to be absorbed by a special membrane.
B) the lighter gas molecules have a greater chance to pass through a special membrane to another chamber.
C) the heavier gas molecules tend to move outward in a rotating container.
D) the lighter gas molecules tend to move to the top when the container is spun.
E) nuclei of U-238 lose some neutrons during the process to become nuclei of U-235.

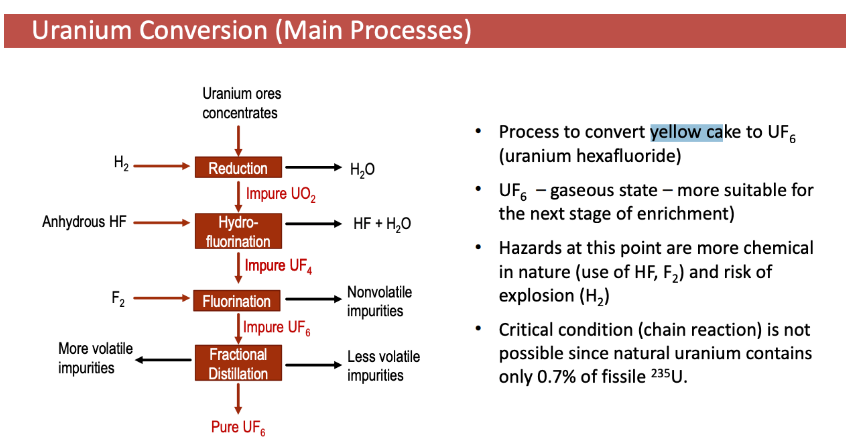
(4) Which of the following statements on reprocessing of nuclear spent fuels is / are true?

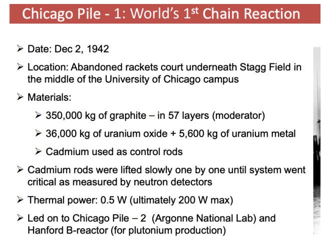
(I) Reprocessing extracts fissile plutonium for use in mixed oxide fuels (MOX).
(II) Reprocessing increases the chance of nuclear proliferation.
(III) Reprocessing reduces the time needed for the radioactivity of the spent fuel to drop to the level of natural uranium ore.

A) (I) only
B) (I) and (II) only
C) (I) and (III) only
D) (II) and (III) only
E) (I), (II) and (III)

(5) The yellow cake (mainly U_3O_8) is converted to uranium hexaflouride (UF6) before the enrichment process. Which of the following statements on this uranium conversion process is false?

A) One hazard of this process is the risk of critical condition where the chain reaction may be maintained.
B) One hazard of this process is the toxic nature of hydrogen flouride (HF) and flourine (F_2).
C) One hazard of this process is the risk of explosion of hydrogen gas (H_2).
D) The need for this process is that UF_6 is in a gaseous state at moderate temperature which makes it more suitable to be enriched by gas centrifuge or gaseous diffusion.
E) Fractional distillation is used during the process to obtain pure UF_6.





Nuclear Weapons and Past Tests

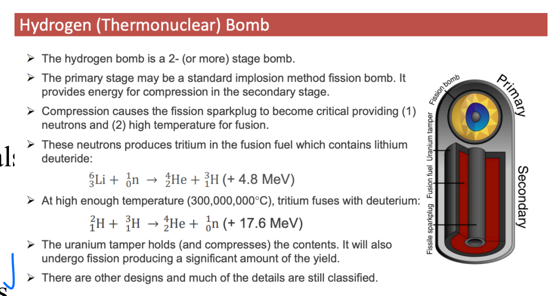
(1) The famous Chicago Pile 1 (CP-1) experiment demonstrated the first human-made self-sustaining nuclear chain reaction in 1942 which led to the atomic bombs and nuclear power reactors. The materials used as the fuel, moderator, coolant and control rods for this experiment are:

	Fuel	Moderator	Coolant	Control Rods
A)	Uranium	Water	Water	Boron Carbide
B)	Plutonium	Water	None	Silver-indium-cadmium
C)	Plutonium	Graphite	Water	Boron carbide
D)	Uranium	Graphite	None	Cadmium
E)	Uranium	None	Sodium	Boron carbide

(2) The atomic bomb that was dropped on Hiroshima is estimated to have a blast yield of 15 kilotons of TNT. Given that each U-235 fission event yields approximately 200 MeV, estimate the mass of U-235 fissioned in the explosion.
[Avogadro constant $N_A = 6.02 \times 10^{23}\ \text{mol}^{-1}$, 1 MeV = 1.60×10^{-13} J, 1 ton TNT = 4.18×10^{9} J]

A) 1 kg
B) 5 kg
C) 25 kg
D) 100 kg
E) 500 kg

$\frac{15\times10^{3}\times4.18\times10^{9}}{1.60\times10^{-13}} \times \frac{1}{200\times10^{6}} = 1.96\times10^{18}$

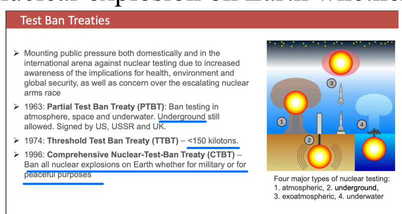


(3) Which of the following statements on the hydrogen bomb is fal

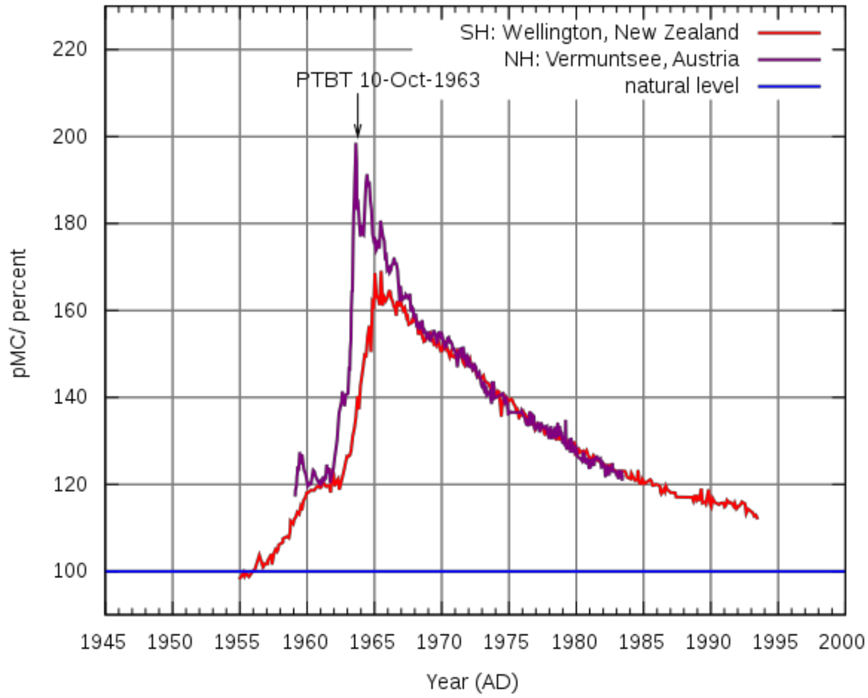
A) The bomb fuses nuclei of hydrogen and helium. √
B) The bomb makes use of both fission and fusion processes. √
C) Lithium is needed to produce tritium for the fusion process. √
D) Its energy yield can be thousands of times higher than the atomic bombs used in World War II.
E) The energy release in a fusion event between two light nuclei is less that than that released in the fission of a U-235 nucleus. ?

(4) The Comprehensive Nuclear-Test-Ban Treaty (CTBT) bans

A) testing of nuclear explosion in the atmosphere.
B) testing in atmosphere, space and underwater.
C) testing of nuclear explosion above 150 kton TNT.
D) all testing of nuclear explosion on Earth except those meant for peaceful purposes.
E) all testing of nuclear explosion on Earth whether for military or peaceful purposes.



(5) The graph below shows the ratio of $^{14}C/^{12}C$ in the earth's atmosphere during the second half of the 20^{th} century. Which of the following statements is **FALSE**?



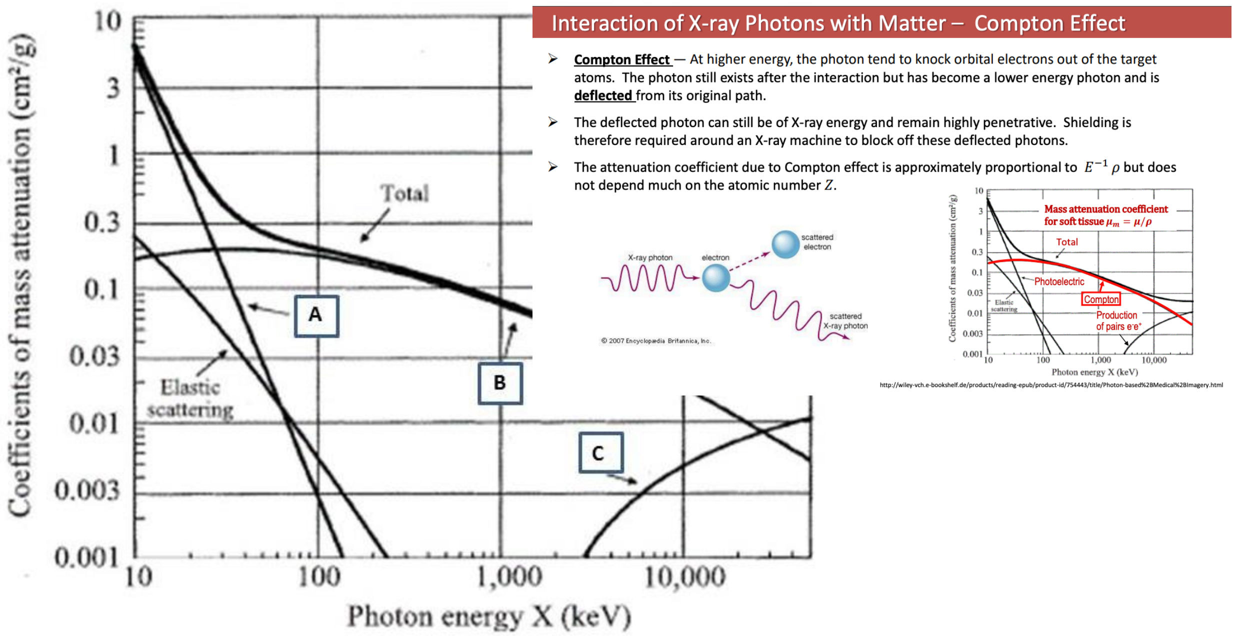
A) The increase during the fifties is due mainly to nuclear weapon tests in the atmosphere.
B) The level stopped increasing in the sixties because atmospheric tests of nuclear weapons was banned.
C) The level of $^{14}C/^{12}C$ dropped because of the natural radioactive decay of ^{14}C.
D) The reason that the level of $^{14}C/^{12}C$ is lower in the southern hemisphere is due mainly to larger bodies of oceans there.
E) The level of $^{14}C/^{12}C$ have been used to verify wine's vintage.

Applications of Radiation – Medical Imaging

(1) Which row of the radiation dose figures are of the correct order of magnitude?

	Radiation dose received by a person in a year from the natural environment	Radiation dose of a common front-view chest X-ray	Radiation dose of a head/neck computed tomography (CT)
A)	0.02 mSv	2 mSv	200 mSv
B)	2 mSv	0.2 mSv	20 mSv
C)	2 mSv	0.02 mSv	2 mSv
D)	200 mSv	20 mSv	2 mSv
E)	0.0002 mSv	0.02 mSv	20 mSv

(2) In the figure below, the physical mechanisms responsible for attenuation of X-ray are:



	Process A	**Process B**	**Process C**
A)	Pair production	Photoelectric effect	Compton scattering
B)	Compton scattering	Photoelectric effect	Inelastic scattering
C)	Elastic scattering	Pair production	Compton scattering
D)	Photoelectric effect	Compton scattering	Pair production
E)	Inelastic scattering	Pair production	Compton scattering

(3) Which row in the table correctly identifies the three medical images below?

	Image (1)	Image (2)	Image (3)
A)	Radiograph (X-ray image)	X-ray Computed Tomography (CT)	Positron emission tomography (PET)
B)	X-ray Computed Tomography (CT)	Positron emission tomography (PET)	Radiograph (X-ray image)
C)	Positron emission tomography (PET)	Radiograph (X-ray image)	X-ray Computed Tomography (CT)
D)	Positron emission tomography (PET)	X-ray Computed Tomography (CT)	Radiograph (X-ray image)
E)	Radiograph (X-ray image)	Positron emission tomography (PET)	X-ray Computed Tomography (CT)

(1)

(2)

(3)

(4) The mass attenuation coefficients of body parts are given below

Photon Energy (keV)	Tissue ($\rho = 0.95\ g\ cm^{-3}$)	Muscle ($\rho = 1.00\ g\ cm^{-3}$)	Bone ($\rho = 1.85\ g\ cm^{-3}$)
10	3.268	5.356	28.51
20	0.568	0.821	4.000
40	0.239	0.269	0.666
60	0.197	0.205	0.315
80	0.180	0.182	0.223
100	0.169	0.169	0.186

The fraction of 40-keV X-ray energy that can pass through 10 cm of tissue is

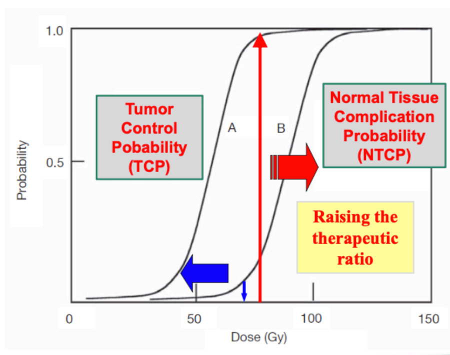
A) about 1%
B) about 5%
C) about 10%
D) about 15%
E) about 20%

$e^{-0.95 \times 0.239 \times 10} = 0.103$

Applications of Radiation – Therapeutic Treatment

(1) The "silver bullet" in radiotherapy refers to the treatment which resulted in

A) The Tumour Control Probability (TCP) = 0 and Normal Tissue Complication Probability (NTCP) = 1.
B) TCP = 1 and NTCP = 0.
C) TCP = NTCP = 0.
D) TCP = NTCP = 1.
E) TCP = NTCP = 0.5.



(2) Which of the following statement(s) about brachytherapy is/are true?

(i) An external beam of high energy electrons is used in the treatment.
(ii) Seeds containing radioisotopes are inserted into the body to provide ionizing radiation to the tumour.
(iii) Brachytherapy is used in treatment of the cancers of prostate gland, cervix and breast.
(iv) Cobalt-60 and iridium-192 are used in this treatment.

A) (i) and (iii) only
B) (ii) and (iv) only
C) (ii) and (iii) only
D) (ii), (iii) and (iv) only
E) (i), (iii) and (iv) only

(3) The advantages of proton therapy over other treatment methods are

(i) Low cost of treatment.
(ii) Minimum damage to the surrounding healthy tissues
(iii) Many patients can be treated at one time.
(iv) Effective in treating difficult areas in body, children and recurrent cancers where standard treatments may not be able to treat.

A) (i) only
B) (i) and (iv) only
C) (ii) and (iv) only
D) (ii), (iii) and (iv) only
E) All of the above

(4) Currently, the three most common radiation sources for external beam radiotherapy are

A) x-ray, gamma rays and accelerated electrons.
B) x-ray, accelerated electrons and positrons.
C) gamma-rays, accelerated electrons and protons.
D) accelerated electrons, positrons and protons.
E) x-rays, accelerated positrons and protons.

(5) Boron Neutron Capture Therapy (BNCT) is emerging as a promising tool in treating cancer. Boron chemical compound which accumulates in cancer cell is injected to a patient. A neutron beam is then irradiated to the lesion and causes the following reaction:

$$^{10}_{5}\mathrm{B}+^{1}_{0}\mathrm{n} \rightarrow ^{7}_{3}\mathrm{Li} + ^{4}_{2}\alpha$$

Which of the above are used to destroy the cancer cells?

A) Alpha particles only
B) Neutrons and alpha particles only
C) Lithium and alpha particles only
D) Neutrons, boron and alpha particles only
E) Neutrons, boron, lithium and alpha particles

BNCT Essentials
1. ^{10}B chemical compound which accumulates in the cancer cell is injected to a patient.
2. The neutron beam is irradiated to the lesion.
3. The cancer cells are selectively destroyed using alpha particle and ^{7}Li particle which are generated by the ^{10}B(n,α)^{7}Li reaction.

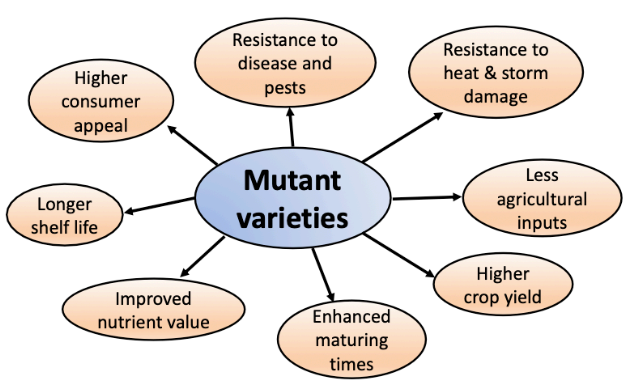
(6) Which of the following statements on the proton beam therapy is false?

A) Proton beam therapy significantly spares of healthy tissues and critical organs of unwanted irradiation, as compared to conventional radiotherapy.
B) Proton beam therapy requires a particle accelerator.
C) Proton beam therapy is expensive and may be limited very few hospitals.
D) Proton beam therapy should not be used to treat cancer in children.
E) Proton beam therapy is especially indicated for cancer treatment of the central nervous system and liver.

Applications of Radiation – Agriculture and Food Production

(1) Which of the following are advantages of mutant variety of crops resulted from irradiation?
(II) Improved nutrient values
(III) Longer shelf life
(IV) Higher crop yield
(V) Resistance to pests and diseases

A) (I) and (III) only
B) (II) and (IV) only
C) (I), (II) and (IV) only
D) (II), (III) and (IV) only
E) (I), (II), (III) and (IV)



(2) Which of the following sources of radiation have been used to produce mutant varieties of crops?

(I) Gamma source such as Co-60 √
(II) X-rays √
(III) Energetic electrons
(IV) Neutrons
(V) Alpha particles

A) (I) and (II) only
B) (I), (II) and (III) only
C) (I), (III) and (V) only
D) (I), (II), (III) and (V) only
E) All of the above have been used

(3) What is the typical dose of irradiation used to extend the shelf life of refrigerated meat, fish and ready to eat meals?

A) 1 – 10 Gy
B) 10 – 100 Gy
C) 100 – 1000 Gy
D) 1 – 10 kGy
E) 10 – 100 kGy

Dose Range for Food Irradiation

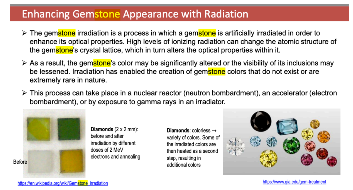
Dose Range (kGy)	Effects	Examples
0.1 – 1 (low dose)	Sprouting inhibited	Potatoes, onions, garlic & yams
	Ripening delayed	Banana and papaya
	Insects unable to reproduce	Fresh produce
	Insects killed	Dried fish, dried fruits and legumes
	Parasites inactivated (helminths and protozoa)	Meat products, fresh fruit and vegetables
1 – 10 (medium dose)	Number of spoilage organisms reduced	Strawberries
	Shelf-life extended	Refrigerated meats and fish, ready to eat meals
	Non-sporulating microorganisms inactivated	Refrigerated or frozen meats, fish and seafood, pre-cut fruit and vegetables
	Microbiological contamination reduced	Spices and dried food ingredients
More than 10* (High dose)	Reduce microorganisms to the point of sterility	Hospital diets, emergency rations and food for astronauts

(4) The working principle of neutron moisture gauges is based on

A) the neutron's ability to form deuterium (H-2) with hydrogen (H-1).
B) the neutron interacting with the oxygen-16 in the water molecules to form oxygen-17.
C) moderation of neutrons by the water.
D) the transfer of energy from neutrons to the surroundings thereby raising the temperature of water which is measured.
E) the evaporation of water in the soil by neutrons.

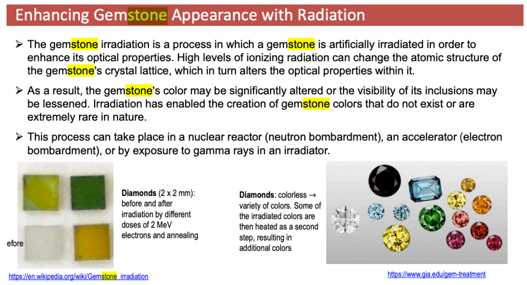
(5) Sterile Insect Technique (SIT) is an effective way to control and eradicate unwanted insects. Which of the following statements about SIT is **FALSE**?

A) To be effective, SIT should be used together with other methods of insect control such as insecticides and traps.
B) SIT does not introduce non-native species into the ecosystem. √
C) Both male and female insects of the species are sterilized through radiation to reduce the number of offspring in the next generation. only male
D) SIT have been used successfully against Medfly and screwworm.
E) Sterilized insects have to be released over a few generations to eradicate these insects.



Applications of Radiation – Industry and Engineering

(1) Various types of ionising radiation are used to enhance the appearance of gemstones. Irradiation by ____________ can result the gemstones remaining radioactive for a short time which requires them to be kept by suppliers until its radiation level is low enough as stated in the country's regulations.



A) beta particles
B) alpha particles
C) x-rays
D) gamma rays
E) neutrons

(2) The nuclear gauges are used to measure liquid level and the thickness of materials. In these applications, which properties of ionizing radiation is used?

A) The ability of the radiation to ionize
B) The ability of the radiation to penetrate different materials
C) The ability of the radiation to cause a change in the chemical property of the materials
D) The ability of the radiation to cause a change in the physical property of the materials
E) The ability of the radiation to cause the nucleus to change from one element to another

(3) Which of the following are differences between medical CT and industrial CT scans?

(I) Medical CT scans usually uses x-ray while industrial CT scan usually uses x-ray $\cancel{\gamma}$-ray.
(II) In medical CT scans, the patient is always held stationary and the imaging system is moved while in the industrial CT scans, the object can be moved while the imaging system is stationary.
(III) Medical CT scans typically take only thousands of images while industrial CT scans can take millions of images.
(IV) In medical CT scans, a 3-d image is formed from various 2-d images while industrial CT scans only allow the users to detect the presence of voids and faults in the object.

A) (I) and (II) only
B) (II) and (III) only
C) (I), (III) and (IV) only
D) (I), (II) and (IV) only
E) (I), (II), (III) and (IV)

(4) Natural silicon contains 3 stables isotopes: 92.2% of ^{28}Si, 4.7% of ^{29}Si and 3.1% of ^{30}Si. There are also traces of radioactive ^{31}Si (β-decay, $T_{1/2}$= 2.62 hrs) and ^{32}Si (β-decay, $T_{1/2}$ = 153 yrs). Irradiation by neutrons is used to convert some of the silicon atoms (Z = 14) to phosphorus (Z = 15). Which isotope of silicon is converted to phosphorus?

A) ^{28}Si
B) ^{29}Si
C) ^{30}Si
D) ^{31}Si
E) ^{32}Si

(5) The neutron moisture gauge is used to measure the amount of water in the ground. When the ground is wet, the number of neutrons detected is

A) low because more neutrons are absorbed by the water.
B) low because the energy of the kinetic energy of the neutrons is quickly reduced through collision with the hydrogen nuclei in water.
C) low because there is less air trapped in the soil which allows the neutron to pass through.
D) high because the hydrogen nuclei in water slows down the neutrons very quickly and more slow neutrons are scattered to the detector.
E) high because there is more air between the soil grains which reflects the neutrons to the detector.

(6) Plutonium-238 is often chosen as the source for both radioisotope heater unit (RHU) and radioisotope thermoelectric generator (RTG). The main reason(s) for this choice is/are

(I) Its half-life of 87 years allows a relative constant energy release for a reasonable length of time.
(II) It is an alpha-emitter making shielding its radiation relatively simple.
(III) It is available in large quantities from operation of nuclear power plants.
(IV) It can be easily obtained in a pure form without the other plutonium isotopes.

A) (I) only
B) (I) and (II) only
C) (I), (II) and (III) only
D) (I), (III) and (IV) only
E) All of the above

Applications of Radiation – Science, Arts & Research

(1) The isotope ^{238}U decays to ^{206}Pb with a half-life of 4.47×10^9 years. Although the decay occurs in many individual steps, the first step has by far the longest half-life; therefore, one can consider the decay to go directly to lead. A rock is found to contain 4.20 mg of ^{238}U and 2.135 mg of ^{206}Pb. Assume that the rock contained no lead at formation, so that all the lead present now arose from the decay of uranium. What is the age of the rock?

$\lambda = \frac{\ln 2}{T} = \frac{\ln 2}{4.47 \times 10^9}$

$N_U = \frac{4.2}{238}$ $\quad N_p = \frac{2.135}{206}$

$\frac{N}{N_0} = e^{-\lambda t}$ $\quad -\lambda t = \ln\left(\frac{N}{N_0}\right)$ $\quad t = -2.9 \times 10^9$

A) 11.2×10^9 years
B) 3.0×10^9 years
C) 4.6×10^9 years
D) 7.0×10^9 years
E) It is impossible as the age of the rock is greater than the age of the Earth.

(2) On September 19, 1991, German tourists on a walking trip in the Italian Alps found a human body trapped in a glacier, later dubbed the Ice Man. The body was dated using the radiocarbon method. Material found with the body had a C-14 activity of about 0.121 Bq per gram of carbon. What is the approximate age of the Ice Man's remains? (Ratio of $^{14}C/^{12}C$ in atmosphere may be assumed to be 1.3×10^{-12}, Avogadro's number = 6.02×10^{23} per mole, half-life of ^{14}C = 5,730 years)

A) 2,000 years
B) 4,000 years
C) 6,000 years
D) 8,000 years
E) 10,000 years

(3) The technique known as potassium-argon dating is used to date old lava flows. The potassium ^{40}K has half-life of 1.28 billion years and is naturally present at very low levels. About 10.7% of the time, ^{40}K decays by electron capture into ^{40}Ar while for the rest of the time (i.e., 89.3%), ^{40}K decays into ^{40}Ca by emitted an electron. Argon is a noble gas, and there is no argon in flowing lava because the gas escapes. Once the lava solidifies, any argon produced in the decay of ^{40}K is trapped inside and cannot escape. A geologist brings you a piece of solidified lava in which you find the $^{40}Ar/^{40}K$ ratio to be 0.12. How long ago did this piece of lava solidify?

A) 210 million years
B) 520 million years
C) 1.4 billion years
D) 2.1 billion years
E) 4.1 billion years

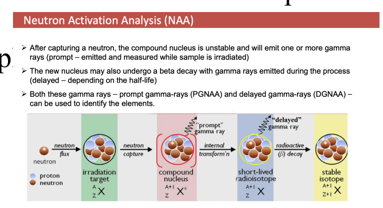
(4) The evidence(s) that a natural nuclear reactor operated at Oklo in Gabon two billion years ago include(s)

(I) Lower percentage of U-235 in the uranium ores from the Oklo mines
(II) Fused rocks in the region due to the heat generated by the reactor
(III) Mutated lifeforms in the areas around the Oklo mines
(IV) Isotopic compositions of neodymium and ruthenium in the area similar to that produced by the fission of U-235

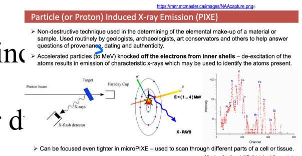
A) (II) only
B) (II) and (III) only
C) (I) and (IV) only
D) (I), (III) and (IV) only
E) (I), (II), (III) and (IV)

(5) Which of the following statements on the neutron activation analysis (NAA) and proton induced x-ray emission (PIXE) is **<u>FALSE</u>**?

A) The spectra from both techniques can be used to determine some of the elements present in the samples.
B) Both techniques probe the nuclei of the atoms in the samp
C) Both techniques are very sensitive.
D) Both techniques make use of ionizing radiation.
E) Both techniques are non-destructive.



(6) Which of the following statements on applications of ionizing radiation is inc



A) Beta radiation is used to measure and control the thickness of paper d manufacturing.
B) Food may be irradiated by neutrons to extend their shelf lives.
C) Neutron activation analysis may be used to determine the composition of materials.
D) Medical equipment are often sterilized by gamma radiation.
E) Radiocarbon dating is often used to date archaeological samples.