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the MICROSCOPIC WORLDS
by Ionizing Radiation

PROFESOR DR. ELIAS SAION

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Contents

Elias Saion

ABSTRACT

A journey from the femto-scale world to the nano-scale world is full of mysteries and enlightening phenomena that inspire further scientific and philosophical debates. Among others, nuclear reactions, radioactivity, atomic structure and molecular bonds are the essence of microscopic worlds, for which accurate descriptions can only be through quantum physics. The fundamental aspect of nuclear radiation is its ability, in a single event, to transfer energy to the nucleus or to orbital electrons. Understanding such interactions and devising techniques that allow them to be manipulated and controlled remains one of the greatest challenges in research that underpins the development of new technologies.

This lecture discusses the fundamental and social aspects of nuclear radiation and reviews the author's experiences in nuclear technologies in three disciplines of physics. For research in nuclear physics, neutron interactions with nuclei were exploited by irradiating marine sediment samples with thermal neutrons in the nuclear reactor. The neutron activation analysis technique was used to determine the concentration of anthropogenic and non-anthropogenic elements to monitor pollution levels. In atomic physics research, interactions of charged particles with tissue matters were calculated prior to the development of a microdosimeter that is able to measure the quantity and quality of radiation in a simulate tissue volume of nm dimensions. In molecular physics research, the desired chemical changes by gamma rays in molecules were used to synthesize functional materials including ionic exchange membranes by radiation grafting, conducting polymers and polymer gels by radiation-induced polymerization and metal nanoparticles by radiation reduction process. This journey has provided exciting prospects where ionizing radiation could be exploited in molecular engineering for peaceful use.

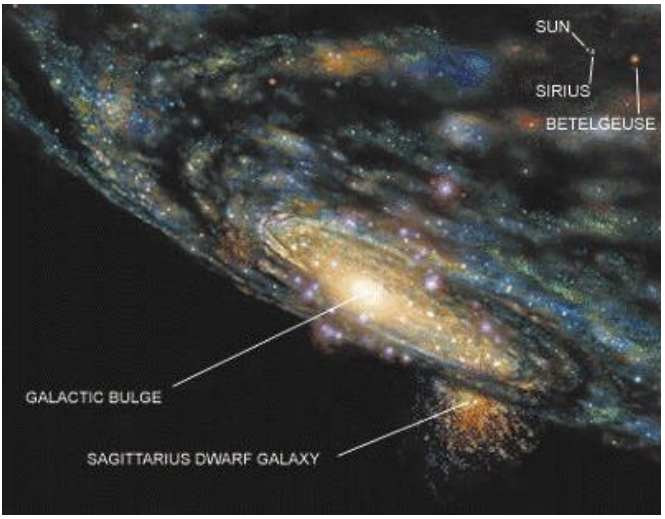
INTRODUCTION

Indeed, I feel immensely honoured and privileged to be provided this occasion to deliver my inaugural lecture on 'Probing the Microscopic Worlds by Ionizing Radiation'. The intellectual elements of this lecture are based on nuclear physics, radiation physics and radiation chemistry, which nowadays are of continuing interest and importance. Nuclear reactors should become the major energy sources of electricity of the future to replace the internal combustion power plants of coal, oil and natural gas whose harmful emissions of carbon dioxide are the major contributors to global warming. Moreover, under the supervision of the International Atomic Energy Agency (IAEA), nuclear radiation has found many peaceful applications in medicine and industry that improve the quality of modern living standards. The description of nuclear radiation probing the microscopic worlds is only made possible by the establishment of quantum physics, a wonder drug to heal physics problems of the early 20^{th} century. The development of quantum physics is a dramatic story, full of human interest and with wide repercussions. One cannot ignore the historical dimension since some knowledge of the past is essential for a full understanding of the present. The physicists responsible for these advances in our knowledge were a truly remarkable and diverse set of characters and they deserve to be forever remembered in history.

Man has been continuously exposed and become accustomed to natural radiation coming from cosmic rays and radioactive substances ever since the beginning of human existence. However, after the discovery of artificial radiation more than a century ago, the benefits and risks of ionizing radiation are questionable. Perhaps, because of the lack of reliable and accessible information and the misunderstandings that surfaced. It is of significant importance to highlight the fundamental and social aspects of nuclear radiation, particularly the sources of ionizing radiation, the benefits and risks,

and the public anxiety resulting from the use of man-made radiation machines and the radioactive substances produced in nuclear reactors.

This lecture also aims to review my academic adventure, which I regard as a journey from the femto-scale world (10^{-15} m, the size of a nucleus) to the nano-scale world (10^{-9} m, the size of a molecule). It represents the opportunities and experiences that I have undergone in pursuing my academic career that enabled me to be conferred a professorship of Applied Radiation. The journey began with probing the nuclei of marine sediments with thermal neutrons. The nuclear activity that was produced was exploited to assess the pollution levels of major, minor, and trace elements along the Straits of Melaka. The subsequent journey involved looking at interactions of charged particles with tissue matters, prior to the development of a microdosimeter for radiation protection purposes. Such a device is able to measure both quantity and quality of radiation in simulated tissue of nm dimensions. The concluding journey occupies ongoing research on radiation processing by gamma irradiation for the synthesis of functional materials such as ionic exchange membranes for fuel cells, polymer gels for 3-dimensional dosimeter, conducting polymers for electromagnetic shielding and sensors and metal nanoparticles for sensors and catalysts. Overall, this journey will highlight the exciting applications of ionizing radiation in molecular engineering for peaceful use.



Milky Way

The Birth of Modern Physics

Nuclear Physics

Modern science tells us that the Universe began from a singularity about 16 billion years ago. The pictures taken by Edwin Hubbell in the Mount Wilson observatory in 1929 showed that the Universe was expanding which led to the Big Bang theory of the creation of the Universe. The first few minutes after the Big Bang saw such extremely high energy (10^{32}K) that all four interactions of physics were unified and all matter contained in quack-gluon plasma, the elementary constituents of protons and neutrons. The Universe rapidly expanded and cooled and was dominated by radiation, until 700 thousand years later when temperature dropped to 16,000 K which allowed protons to bind to electrons to form neutral hydrogen atoms. Radiation no longer dominated the Universe, and clumps of neutral matter steadily grew - first atoms, then molecules, gas, clouds,

stars and galaxies. The Universe continues to expand and what will happen next? All matter may be ripped off leaving the Universe empty and in darkness.

Nuclear and quantum physics developed at about the same period, beginning at the end of 19th century. Nuclear physics developed out of the discovery of radioactivity from potassium uranyl sulphate by Becquerel in 1896 and from uranium and thorium salts by Marie and Pierre Curie in 1898. Rutherford, in 1898, found radioactive substances that emit α-particles and β particles. Two years later in 1900 Villard discovered the third type of nuclear radiation, i.e. gamma rays. For his investigation of radioactivity of nuclear substances Rutherford was awarded the Nobel Prize in physics in 1908. Using α-particle scattering experiments, Rutherford, in 1911, found that the atomic structure consists of a nucleus at the centre. Continuing with his studies, in 1919 he discovered positive charged particles emitted from the nucleus, which he called protons. Bothe and Becker, in 1930, bombarded beryllium with α-particles and found that a very high energy radiation of about 4.5 MeV is emitted. In 1932, Chadwick realized that penetrating radiation consists of particles having nearly the same mass as protons, which he called neutrons.

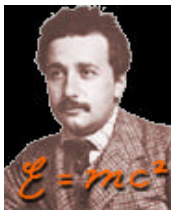
The fundamental constituents of the nucleus are protons and neutrons, which are called nucleons. These nucleons can be excited and the interactions between them mediated by pions and other unstable elementary particles. The first neutron reactor was built by Fermi in 1942, which led to the development of nuclear bombs (not atomic bombs) sometime, perhaps before August 6, 1945, the date when the first nuclear bomb was dropped on Hiroshima during the Second World War. In atomic physics, X-rays was discovered by Roentgen in 1896, which was followed by the discovery of electrons by Thomson in 1910. The electronic structure was modelled by Bohr in 1913, which describes the truth of quantum physics. In 1934 Curie and Joliot found positron, a particle with mass equal to

the mass of electrons but positively charged and originating in the nucleus. Positron must meet electron and together they give out two lights in opposite directions. Positron is anti-matter of electron. In particle physics, for each charged elementary particle there exists an anti-particle, a species with an opposite charge but with all other properties strictly identical.

> *All Extolment be to Him, Who created all the pairs of what the earth grows, and of themselves, and of what they do not know (Yasin; 36)*

QUANTUM PHYSICS

Planck



Einstein

de Broglie

The fathers of Quantum Physics

Before 1900, physical phenomena were described in terms of classical physics: mechanics, thermodynamics, statistical mechanics and electromagnetism. Scientists discovered that classical theories failed to explain some physical phenomena such as black body radiation and stable electron orbits. At a meeting of the German Physical Society on December 14*th*, 1900, Mark Planck speculated that the energy of black body radiation is quantized or discrete in the form: $E = 0,\ \Delta E,\ 2\Delta E,$ where $3\Delta E,...$ is the uniform interval

between successive allowed values of the energy, is the frequency, and $h = 6.03\times10^{-34}$ joule.sec, is a universal Planck constant, which characterizes quantum physics. Planck was awarded the Nobel Prize in physics in 1918. Earlier in 1987, Heinrich Hertz performed an experiment that first confirmed the Maxwell's electromagnetic theory of light propagation. In his experiment, Hertz noted the ejection of electrons from the metal surface of a cathode ray tube by the action of light, known as the photoelectric effect. In 1905 Albert Einstein called into question the classical theory of light and he proposed that the light quanta of energy (or photons) that propagates with velocity c, should have the energy content related to its frequency, ν given by $E=h\nu$. He was able to use the quantum concept of the discreteness of energy in predicting, theoretically, the law of the photoelectric effect - an idea that won him the Nobel Prize in physics in 1921.

Further, in 1905 Einstein established the concept of mass-energy relationship, where for a particle of mass m, its total relativistic energy given by $E=mc^2$, where c=3.00 x 10^8 meter.sec^{-1} is the velocity of light in vacuum. I believe it is now one of the most famous equations familiar to both scientists and the general public even though they might not understand its actual meaning. For a particle at rest, having a rest mass m_0, the rest mass energy is given by $E_0 = m_0c^2$. The relativistic energy of a particle is equal to its kinetic energy K and its rest mass energy E_0, i.e. $mc^2 = K + m_0c^2$. I wonder, if a nuclear bomb would have ever been developed, if Einstein did not establish the existence of matter-energy relationship in the theory of relativity. In the relativity theory, there is no such thing as an absolute time interval.

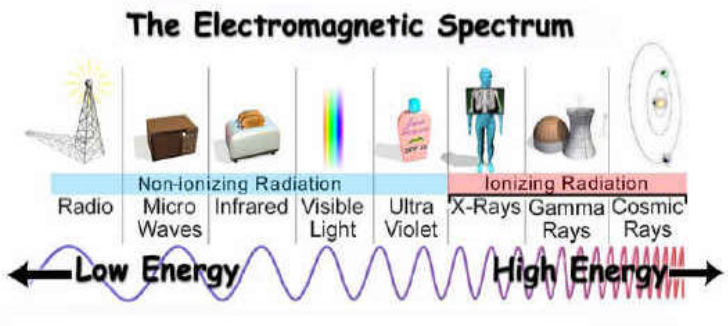
He conducts the Command from the heaven to the earth; thereafter it winds up to Him in one Day, whose determined (length) is a thousand years of what you number (As-Sajdah;5)

In 1924, Louis de Broglie proposed the existence of matter waves, given by the matter wavelength as $l = h / p$, where p is the momentum of the matter. In 1929 he was awarded the Nobel Prize in physics. Einstein who had earlier proposed energy of photons, recognized the importance and validity of the wave-particle duality concept and brought them to the attention of the physicist community. In microscopic dimensions the dual wave-particle hypothesis applies equally well to radiation (wave) and particles (matter). For particles and radiation alike, the matter concepts are connected through the Planck constant h to the wave concepts. Thus, $E = h\nu = hc / l = pc$. The wave-particle duality was completed by another quantum concept - the Heisenberg uncertainty principle proposed in 1927, which puts the limit of both the position and the momentum. Heisenberg was awarded the Nobel Prize in physics in 1932.

Elias Saion

NATURAL AND ARTIFICIAL RADIATION SOURCES

What is Ionizing Radiation?



Radiation may be divided into two general categories, namely ionizing radiation and non-ionizing radiation. Non-ionizing radiation are electromagnetic waves that have no ability to cause ionization of the atom including ultra violet (UV), visible light, infrared (IR), laser, radio frequency (RF) and microwaves. The physics governing the interaction of non-ionizing radiation with matter is by thermal vibration or heat. Ionizing radiation is energy in transit in the form of electromagnetic waves (X-rays and γ-rays) or high-velocity charged particles (electrons, β-particles, protons, α-particles) or high-velocity uncharged particles (neutrons). Ionizing radiation has the ability in a single energy transfer event to ionize atoms.

Man has been exposed to natural radiation from cosmic rays and radioactive substances and to artificial radiation from radiation machines and man-made radionuclides as shown in Table 1.

The quantity of radiation energy absorbed or dissipated in materials per unit mass is the absorbed dose or the dose and is measured in gray (Gy). Equal doses of different types of radiation do not necessarily produce equal biological damages. For example,

Table 1 Classification of natural and artificial radiation

Category	Source/Machine	Type of Radiation
Natural Radiation	Cosmic rays	protons, α–particles, neutrons, pions, muons, electrons, and γ-rays
	Radioactivity	α -and β-particles, γ-rays
Artificial Radiation	High voltage X rays	kV X rays
	Linac/Betatron	MV X rays, electrons, radioactivity
	Van de Graaff and Cyclotron	protons, neutrons, radioactivity
	Synchrotron	electrons, protons, X- rays
	Nuclear reactor	neutrons, γ-rays, radioactivity
	Radioactivity	α -and β-particles, γ-rays, neutrons

1 Gy of α-particles will produce more severe biological effects than 1 Gy of γ--rays or β -particles by the quality factor of 20. The relevant parameter, taking into account both the quantity and quality of radiation, is therefore the dose equivalent which is measured in sievert (Sv).

Natural Radiation

Ionizing radiation is an inseparable part of the living environment on earth and in space. Man has been continuously exposed to natural radiation from cosmic rays originating from outer space and the sun and from radioactive substances found in the soils, rocks, water and air on earth. Cosmic rays consist of mostly protons, about 10%

particles, and others 1% comprising of electrons, neutrons, pions, muons, ions, and γ-rays. Low energy cosmic rays come from solar flares of the sun while those of high energies come from our own galaxy, the Milky Way. Since, most cosmic rays are charged particles the number entering the atmosphere is affected by the Earth's magnetic field. The dose rate increases as latitude increases. The poles receive higher doses than the equator. Secondary cosmic rays are produced as a result of the primary cosmic rays penetrating the atmosphere and interacting with the atoms and molecules in the atmosphere. The dose rate decreases as altitude decreases. At ground level, cosmic rays are primarily muons and electrons that give annual dose equivalent to about 0.4 mSv. People who live at high altitudes such as the Andes and the Himalayas may receive annual doses five times the global average. Frequent air travellers, might receive 100 times higher doses than those at ground level.

Radioactive substances decay according to uranium, thorium, and actinium series to produce nuclear radiation α–particles, β–particles and γ- rays. Uranium-238, which is dispersed throughout rocks and soils, decays in succession until the stable nuclide lead-206. Among the decay products in the series is gas radon-222, which can reach the atmosphere. Radon decays to liberate short-range α-particle. In another decay series, Thorium-232, the decay product is gas radon-220. Radon radionuclides with short half-life enter the atmosphere from the ground to attach themselves to fine particles in the air, which when inhaled increases the risk of lung cancer. The annual average dose equivalent globally, due to the decay product of radon, is about 1.2 mSv. Other radionuclides such as polonium-210, potassium-40 and carbon-14 are present in air, food and water. Through food chains they contribute to internal radiation with the annual average dose equivalent of about 0.3 mSv. The United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR) was established in 1955 to estimate potential health risks. The global average annual dose equivalent is 2.8 mSv from

which the natural radiation sources contribute about 2.4 mSv, as shown in Table 2.

Table 2 Global average annual dose equivalent

Category	Source	Dose equivalent (mSv)	Total
Natural Radiation	Cosmic radiation	0.4	
	Gamma radiation	0.5	
	Radon inhalation	1.2	
	Internal irradiation	0.3	2.4 mSv
Artificial Radiation	Medical	0.4	
	Nuclear testing	0.005	
	Chernonyl fallout	0.002	
	Nuclear power	0.0002	0.4 mSv

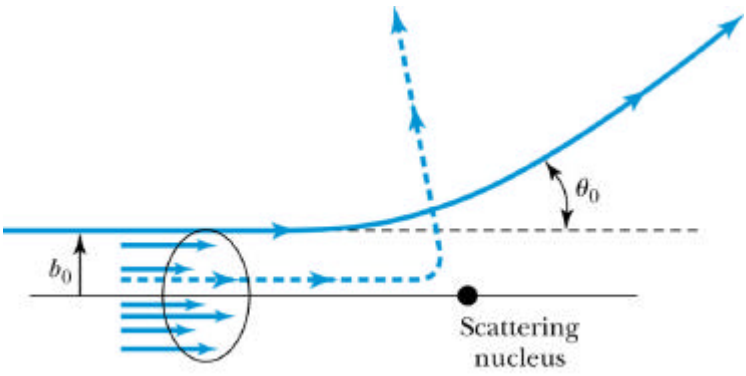
Artificial Radiation

In addition to natural radiation sources, in modern society, man is also exposed to many artificial radiation sources including man-made radioactive substances, X-rays in medical check ups, high-energy radiation from radiotherapy treatment, radioactive fallout from nuclear explosions, contamination from nuclear reactor accidents and consumer goods containing radioactive substances. Man-made radiation machines used for medical applications are found in radiology, dentistry, nuclear medicine and radiotherapy. Artificial radiation sources in the nuclear industry come from uranium mining, milling, and enrichment, fuel fabrication, nuclear reactors and reprocessing of fuel. An explosion in a nuclear reactor at the Chernobyl nuclear reactor plant at Ukraine on 26 April 1986 caused the release of substantial quantities of radionuclides throughout Europe and beyond. However, it still contributes a small amount of dose equivalent to the population.

As estimated by IAEA, there are about 800 thousand workers in the nuclear industry worldwide and over 2 million workers in the medical facilities who are expected to receive more than the annual average dose equivalent of 0.4 mSv, due to artificial radiation. For radiation protection purposes, the annual dose limits for radiation workers are 20 mSv for whole body exposure, 500 mSv for individual organ or tissue or hands, and 150 mSv for lens of the eye.

FUNDAMENTALS OF NUCLEAR RADIATION

Radiation Interactions - Physicals



Charged particle interactions with matter

Study of radiation interactions with matter is fundamental in many aspects of radiation physics in order to explore the effects and detection of radiation. Radiation interactions are highly complex chains of events that are governed by many physical parameters including the charge, energy and mass of radiation, as well as the

charge and mass of the target atom. We may classify radiation interactions based on radiation types.

A particle is categorized as fast when its velocity ν is larger than the velocity of the orbiting electron, $v_e = v_0 Z^{2/3}$, where v_0 is the orbital velocity of the ground state electron in a hydrogen atom ($v_0 = e^2/\hbar = 2.18\times10^6\ m\,s^{-1}$) and Z is the atomic number of the particle. The incident particle is categorized as slow when its velocity ν is less than the orbital velocity $\nu < \nu_e$. The fundamental mechanism in which charged particles lose their energy in matter is either via elastic or via inelastic collision with the atom or nucleus. Fast heavy charged particles collide predominantly with the orbital electrons by Coulomb force to produce a straight line path. On the other hand, slow heavy charged particles passes near the nucleus by nuclear force and produces recoil particles having the path length of a zig-zag pattern.

Sufficient energy is transferred to the electron to produce excitation or ionization. When the atom is ionized the electron is removed completely. The electron may have sufficient energy to produce further ionization. Such energetic electrons that produce secondary ionization are called δ-rays.

Fast light charged particles such as β-particles and high speed electrons, can lose energy by ionization or excitation in a manner similar to that of heavy charged particles but the particle track is the zig-zag pattern. Electrons can also lose energy by bremsstrahlung from which continuous X-rays are emitted due to deceleration of electrons by the target nuclei.

Electromagnetic radiation such as β-rays and X-rays, interact with matter by absorption and scattering processes. Photoelectric is an absorption process whereby photon of energy from 10 keV to 150 keV loses all its energy to a bound electron, which is then emitted as a photoelectron. Compton incoherence scattering is dominant at energies between 20 keV and 10 MeV, where photon interacts with an unbound electron to produce recoil electron and

scattered photon of reduced energy. Rayleigh coherence scattering occurs at low energies below 50 keV by which photon is scattered without losing the energy. For photons of energy greater than $2 m_e c^2$ or 1.02 MeV, they lose energy to the nucleus by emitting electron-positron pair.

For uncharged neutrons of high and medium energy, the interaction is predominantly by elastic scattering with the target nuclei to produce recoil charged particles mainly protons and heavy ions. Neutron interactions by inelastic scattering produces recoil charged particles and γ-rays. The scattered neutrons continue to slow down until they thermalize at room temperature. Captured neutrons are significant for thermal neutrons that lead to the formation of unstable radionuclides and radioactivity.

Radiation Interactions - Chemicals

Ionizing radiation interacts with atoms or molecules for the formation of very reactive intermediates in the form of excited states, ions and free radicals. The electrons that are produced by ionization easily attach to molecules to produce free radicals, which initiate various chemical reaction processes such as polymerization, crosslinking and grafting without a need for catalysts or additives. Sufficient radiation energy can transfer to molecules and cleave the covalent bonds where the sensitivity is governed by the bond's sensitivity to radiation. Halogen derivatives of hydrocarbons such as C-Cl and C-Br are more radiosensitive and can get broken more easily than C-H, C-C and C-OH. At high doses this leads to degradation of high mass molecules such as cellulose, rubber and other polymers where C-C bonds are broken and the molecular mass of the materials reduced.

Water is essential for life. All living things are made up of 70-90% water. When a water molecule is ionized it produces positive charged water molecule, H_2O+ and a high speed electron, e^{-}. This

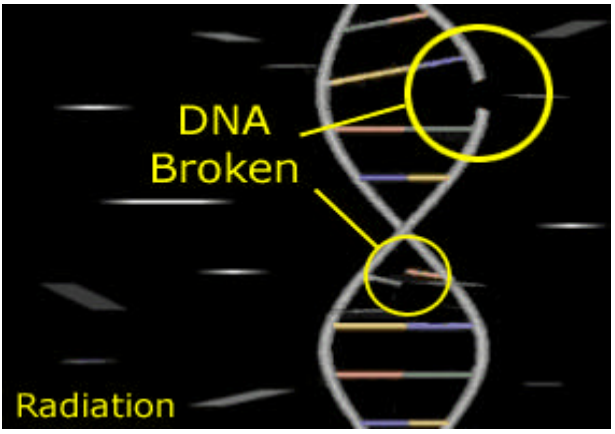
electron will attach to another water molecule to form negative charge water molecule, H_2O^-. Both charged water molecules are unstable and produce OH · and H · free radicals. These radicals are uncharged and very reactive. They react with other radical molecules, R, monomer, M or polymer, P to form other species of molecule radicals, R ·, M · or P ·. These radicals will react with other molecules to form new molecule radicals.

When the molecule radicals react with a monomer, M, the following chemical process is capable of initiating polymerization such as RM ·, MM · or PM · (Rosiak, 2003). Copolymerization can take place during polymerization when different monomers M_1 and M_2 are built in the same backbone of the polymer chain or $P=M_1M_2M_1M_2$…. However, when copolymerization does not occur on the same chain, one polymer P_2 crosses the other polymer P_1, and crosslinking is established or $P_1P_2P_1$. For molecule radicals of high molecular mass polymer P, it can lead to grafting by a low molecular mass polymer, MM attached to the massive one or PMM... (Berejka, 2003).

Hence, ionizing radiation only initiates the ionization and bond scission processes before formation of molecule radicals and subsequent chemical reactions can take place.

And have not the ones who disbelieved seen that the heavens and the earth were an integrated mass, then We split them apart, and of water We have made every living thing. Would they then not believe?(Al-Anbiya; 30)

Biological Effects



DNA stranded breaks

Radiation of different doses, delivered at different dose rates to different parts of the body, can cause different types of biological effects at different times. Biological effects are concerned with accidental exposure, unless for the purpose of radiotherapy treatment.

Following chemical reactions, radiation can cause biological damage by the radicals reacting with organic molecules in the cell structure or by the bond scission that leads to further chemical reactions and biological effects. The radiation scission or the subsequent chemical reactions might either destroy the DNA that leads to cell death, or damage the DNA structure which leads to cell malfunctions such as uncontrolled division or repair. A single-stranded DNA break is repairable but a double-stranded DNA break is beyond repair. When the damage is to the DNA of the gonads, genetic effects such as sterility and Down's syndrome might occur over time.

Ionizing radiation causes two categories of biological effects. Non-stochastic or deterministic effects are those where the severity

of the effect varies with the dose and have a threshold. Examples of acute non-stochastic effects (acute somatic effect) are short term effects such as nervous system (>6 Sv), gastrointestinal syndrome (3-6 Sv), nausea, vomiting, and immunization break down (1-3 Sv) and bone marrow death (0.25-1 Sv). The long term somatic effects are lung and bone cancer, leukaemia or premature aging (<2 Sv), cataract of the eye lens (2 Sv), temporary sterility for men (2 Sv) and permanent sterility for men (8 Sv).

Stochastic effects are those with the probability of an effect occurring, rather than its severity, and are regarded as function of a dose, without threshold. An example of stochastic effects is chromosome aberration (genetic effect).

Is food irradiation safe?

Food irradiation is a process where ionizing radiation is used to kill pathogens such as bacteria, viruses, parasites, and other harmful substances in food by causing breaks in the cell's DNA and which helps to extend shelf-life (IFIC, 2007). It is a safe process which

has been approved by around 50 countries worldwide and is applied commercially in the developed worlds. Approved irradiated foods include fruits, vegetables, meat, poultry, fish and seafood, roots and tubers, cereals, legumes, spices and dry vegetable seasoning. Food is irradiated in an enclosed irradiation chamber in an irradiation facility either with a gamma radiation source like Cobolt-60 or Cesium-137 or an electrical source like an electron beam or X-rays.

The purpose of low dose applications below 1 kGy is to control sprouting, ripening, and insect disinfection. For the medium dose applications of 1-10 kGy, preservation is the objective, by destroying spoilage and pathogenic microbes to improve shelf-life of meat, poultry, and seafood under refrigeration. Sterilization of packaged meat, poultry and their products can be achieved at high dose applications of above 10 kGy. Since, γ-rays, X-rays or electrons do not have enough energy to affect the neutrons in the nuclei of irradiated molecules therefore irradiation does not make food radioactive, compromise nutritional quality, or noticeably change taste, or texture, or appearance of food for a suitable product. However, irradiation cannot be used with all foods such as dairy products, and some fruits like peaches.

Radiation Risks

A person gets sick or disease may come from many causes and radiation exposure is only one. Being exposed to something that can cause disease does not always mean that a person will develop that disease. Radiation risk means the chance of damage, disease or unwanted effects to health due to ionizing radiation. Scientists may estimate a person's risk of getting a disease from radiation exposure based on many factors such as radiation dose and the relation between dose and disease or the dose-response relationship. Linear dose-response means that as the dose increases by a certain

amount, the risk is also increased by a similar amount. At low doses, typical of cancer formation, there is no threshold. Thus, no one knows the exact dose-response relationship at low doses. However for radiation protection standards the linear dose-response relationship is taken to protect public health.

How far will radiation exposure increase the chances of a person dying from cancer during his lifetime?

According to the Biological Effects of Ionizing Radiation committee V (BEIR V), the risk of cancer death is 0.08% per rem for doses received rapidly (acute) or 0.04% per rem for doses received over a long period of time (chronic). 1 rem = 0.01 Sv. Suppose from 10,000 US citizens, about 2,000 of them will die of cancer. If the population of 10,000 is exposed to 1 rem to their whole body, about 0.08%*10,000*1 rem or 8 will die of cancer due to radiation, that is a risk of 8 additional deaths in the group of 10,000 people.

One may consider the level of risk by the number of days lost in the population due to early death from a given cause. Table 3 shows estimated life expectancy lost between populations and

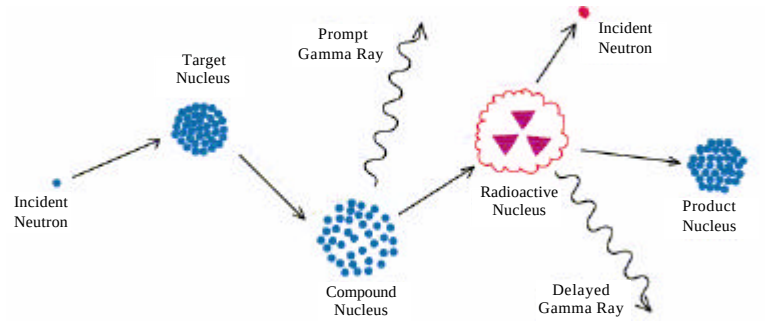
Table 3 Estimated life expectancy lost time

Health risk	Life expectancy lost	Industry type	Life expectancy lost
Smoking 20 cigarettes a day	6 years	All industries	60 days
Overweight (15%)	2 years	Agriculture	320 days
Alcohol (USA)	1 year	Construction	227 days
All Accidents	207 days	Mining and quarrying	167 days
Natural Hazards	7 days	Manufacturing	40 days
Radiation workers (0.01 Sv/year)	51 days	Radiation workers (0.01 Sv/year)	51 days
Radiation workers (3 mSv/year)	15 days	Radiation workers (3 mSv/year)	15 days

between industries. Under normal circumstances ionizing radiation is not so risky after all.

Neutron Activation Analysis

Neutrons, being uncharged, are not attracted by atomic electrons and consequently they interact almost solely with the nuclei of matter either by elastic collisions where energy is conserved or by non-elastic collisions where energy is not conserved. Fast neutrons lose energy and are progressively slowed down by nuclei to intermediate energy neutrons until they eventually reduce in velocity to an average speed of corresponding to the energy of 0.025 eV as thermal neutrons. The principle of neutron activation analysis (NAA) is to target the nucleus with thermal neutrons in the nuclear reactor. When the neutron is captured or absorbed by the nucleus, a highly excited compound nucleus is formed which decays by emitting γ-rays. This reaction can take place with almost all isotopes and has no threshold (Attix, 1986). The ability of a nucleus to capture the neutron depends on the neutron energy and the absorption cross section. By measuring the spectrum of γ-rays, the concentration of radioisotopes may be determined.



Principle of NAA

NAA is used as a multi-element analysis technique because of its accuracy and precision (Zhang et al., 2005). The number of counts of the gamma spectrum of irradiated nucleus at time t is given by

$$C = e\ m\ f\ I_g f\ s\ N_A \left(1 - e^{-lt_1}\right) e^{-lt_d} \left(1 - e^{-lt_c}\right)$$

where ε is the geometrical efficiency of the detector, m the mass of radionuclide of irradiated sample, f the abundance of the radionuclide, I_γ the intensity of gamma line of the element, N_A Avogadro's number, λ decay constant of the radionuclide, ϕ the flux of neutron, σ the activation neutron cross-section, t_1 irradiation time, t_d decay time and t_c counting time.

Monitoring the pollution levels

The Straits of Melaka is the longest and narrowest straits in the world (1,100 km in length and 15-400 km width) and also one of the busiest waterways in the world, where 80% of Malaysian trade passes through it. More than 60% of the fish landed in Malaysia comes from the Straits of Melaka. A total of more than 4,000 industries were identified as significant water pollution sources for the Straits of Melaka.

Most of the environmental pollution studies in Malaysia were carried out using atomic absorption spectroscopy (Ismail, 1993, Yap, 2003). The evaluation of pollution using the NAA method is very limited (Wood et al., 2004). We successful applied the NAA technique to study the environmental pollution by assessing marine sediment samples along the Straits of Melaka (Al-Zahrany, et al., 2006). The sources of pollution may come from natural sources originating from river runoff, rainfall, floods and chemical weathering of crustal rocks, which are called non-anthropogenic, as well as

from non-natural sources originating from human activities such as industries, urbanization, agriculture and fishing activities and mining processes, which are called anthropogenic.

A total of 39 grab marine sediment samples from 16 sampling locations were collected along the Straits of Melaka from Rengit to Pulau Langkawi. An additional 87 core marine sediment samples were collected from 21 layers at 2cm depth for each layer obtained from 4 sampling locations located offshore of Pelabuhan Klang and Pulau Pinang. The radioactivity of 27 heavy elements was determined by NAA while 8 other elements having small neutron cross-section were analysed using Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS). The grab and core samples were used to interpret the horizontal and vertical elemental distributions respectively.

The non-anthropogenic elements were identified by their enrichment factors of less the unity. They are Al, Ba, Ca, Cd, Co, Cr, Cu, K, Mg, Mn, Mo, Na, Ni, Rb, Sr, Ta, Ti, V, and Zn. On the other hand, the anthropogenic elements have enrichment factors greater than unity. They are As, Br, Ca, Cs, Fe, Hf, Pb, Sb, Th, and U which were found to pollute the Straits of Melaka, most likely due to human activities along the west coast of the Malaysian Peninsular (Al-Zahrany et al., 2007). The rare earth elements from the core sediment samples are Ce, Eu, La, Lu, Sc and Sm. The toxic elements As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Sb and Zn were found in concentrations which were lower than the international guidelines of Canada, Netherlands and USA-New York State (Saion et al., 2007, Al-Zahrany, 2007).

RADIATION PROTECTION

Radiation protection is concerned with the protection of man and his environment from unnecessary radiation exposure without eliminating the beneficial applications of radiation and radioactive

materials. The aim is to prevent detrimental non-stochastic effects and to limit the probability of stochastic effects to levels deemed to be acceptable. The principle of radiation protection is that all exposure shall be kept as low as reasonably achievable - the ALARA principle. However, in doing this economic and social factors must be taken into account.

The general practice of radiation protection is to limit doses for individuals so as not to exceed an annual dose equivalent limit of 500 mSv, except for the lens of the eyes where the limit is 150 mSv. Three basic principles to prevent or control exposure to radiation hazards are (i) remove the hazard, (ii) guard the hazard, and (iii) guard the worker. Protection from external radiation hazards includes optimizing the distance from the radiation source; reducing time spent in the vicinity of the source; and use of appropriate shielding between the source and the worker.

Heavy charged particles interactions with atoms

When intermediate energy neutrons (<100 keV) interact with materials such as tissues, heavy charged particles mostly protons and a smaller amount of high-speed ions like C, N, and O are produced. Various interaction processes follow, such as elastic and inelastic collisions with nuclei or electrons and chemical binding effects. The short-range recoil particles have ranges of less than the cellular dimension of most mammalian cells and are capable of producing significant biological damage.

Probing the microscopic matter resulting from these charged particles interacting with tissue matters is a complex phenomenon which may be measured in terms of stopping power and projected range for heavy charged particles interacting with atoms of the tissue. We used the effective stopping power, ${}^{i}S_{j}^{eff}(E)$ and the

corresponding effective projected range, ${}^{i}R_j(E)$ to describe the interaction parameters given by

$$ {}^{i}S_j^{eff}(E) = {}^{i}Se_j(E) + \frac{{}^{i}Sn_j(E)}{2g\,f(x)} $$

$$ \frac{1}{{}^{i}R_j(E)} = \frac{1}{{}^{i}Re_j(E)} + \frac{1}{2g\,f(x)\,{}^{i}Rn_j(E)} $$

where $g = 4m_i m_j/(m_i + m_j)^2$ and $f(x)$ is a function, which converts the nuclear stopping power into the effective nuclear stopping power and the corresponding projected range. The projected range can be calculated from the stopping power as

$$ {}^{i}R_j(E) = R_0 + \int_{E_0}^{E_{\max}} \left(\frac{dE}{{}^{i}S_j^{eff}(E)} \right) $$

The effective stopping powers and projected ranges of heavy recoil ions (i.e. protons, C, N, O) in tissue constituents i.e. hydrogen, carbon, nitrogen, and oxygen) have been calculated using Ziegler's screening length (Ziegler et al., 1985). The theoretical results were compared with available experimental data and found to be in good agreement throughout the energy range from 0.1 keV to 1 MeV (Saion, 1991, Saion and Watt, 1992). The results have been used to determine the effective stopping powers and projected ranges of heavy recoil ions (i.e. protons, C, N, O) in tissue and tissue equivalent (TE) materials. These data are useful to understand how neutrons interact with tissue for radiation protection purposes.

Microdosimeters to simulate tissue of nm dimensions

Is there a device small enough to be inserted into the tissue volume to simultaneously measure the quantity and quality of radiation? The answer is that there is no such device.

In radiation biophysics, we could measure the quantity and quality distributions of radiation energy deposition within a simulated tissue volume (nm dimensions) using a tissue-equivalent proportional counter (TEPC) of much larger size (cm dimensions) in mixed fields. The TEPC comprises of A-150 tissue equivalent (TE) plastic wall to allow a prevision for secondary charged particle equilibrium and TE gas of low pressure used for interacting medium and counting gas (Rossi et al., 1961, ICRU 1983). The simulated mean chord length for spherical and cylindrical tissue volumes of density 1 gcm^{-3} in gas cavity of pressure P_g (torr) may be determined by

$$\bar{l} = \frac{2}{3} d_g r_g \left(\frac{P_g}{760} \right) \qquad \text{(spherical volume)}$$

$$\bar{l} = \frac{2 r_g h_g}{\left(r_g + h_g \right)} r_g \left(\frac{P_g}{760} \right) \qquad \text{(cylindrical volume)}$$

where d_g is the diameter of spherical microdosimeter and r_g and h_g are the radius and length of cylindrical microdosimeter respectively. Having a TEPC operated at very low gas pressure, typical of several torr, simulated tissue volume of 14 nm has been achieved (Colautti et al., 1985).

There are limited devices that enable the measurement of the quantity and quality of radiation in mixed fields of many nuclear radiation components such as fast neutrons and intermediate energy neutrons. Ability to discriminate dose equivalent due to intermediate energy neutrons in mixed fields of faster neutrons and gamma rays will be useful in the vicinity of nuclear reactors and accelerator

installations. For this, a novel microdosimeter co-axial double cylindrical TEPC consisting of a 8-anode outer TEPC and single anode inner TEPC was constructed (Saion and Watt, 1994). The thickness of the dividing wall is important to discriminate intermediate neutrons from fast neutrons. For proton recoils generated from neutrons of 100 keV and 800 keV, a dividing wall with thickness of 1.25 m and 14.4 m respectively are needed. The dividing walls were made from TE plastic films cast from TE powders at 170 °C by compression (Saion et al., 1992). The inner TEPC should work in anti-coincidence with the outer TEPC. The sensitive volumes of less than 50 nm were obtained using the TEPC inner counter of diameter 1.6 cm. Even at a simulated tissue size of about 10 nm, the basis of the radiation action is the energy deposition, which might not explain the true nature of radiation action that causes tissue damage by DNA.

Finally, the smallest simulated mean cord length of 1.85 nm simulating tissue volume of a double-stranded segment of the DNA has been successfully achieved using a cylindrical TEPC counter with diameter of 1 cm by our colleagues (Tamboul and Watt, 2001). In their analysis, the radiation risk is no longer due to energy deposition for radiobiological damage in tissues, instead it is due to specific ionization spacing or biological geometry cross-section occurring at the radiosensitive sites of 2 nm which is superimposed with the double-stranded DNA in the nucleus of tissue cells. In this interpretation single and double-stranded breaks are likely to occur when ionizations are created at 2 nm spacing or less (Watt, 1989).

RADIATION DOSIMETERS

High Dose Radiation Dosimeters

Interest in food irradiation technology for preservation of food and to improve the hygienic quality of food is increasing worldwide and

in some developed countries commercialisation of food irradiation has already become a reality. A reliable dosimetry system is necessary to satisfy regulatory requirements and for quality assurance. As routine dose monitoring in radiation processing, polymer dyed flexible films are considered to be the most common as dosimeters, dose labels and indicators (Ebrahem et a., 2002). Various dyed polymer films have been developed to measure higher doses in neutron, γ-rays, and electron beam facilities (Abdel-Fattah et al., 1996, Baraket et al., 2001). Blend polymers such as poly (vinyl butyl) (PVB) or poly (vinyl chloride), organic compounds containing chlorine such as chloral hydrate and acid-base indicators, are commonly used to prepare the dosimeters by mixing in solvent, cast and drying into films.

In this work, poly (vinyl alcohol) (PVA), chloral hydrate and cresol-red indicators were used to prepare the film dosimeters (Saion et al., 2004 a). Other ionic and organic compounds such as trichloroacetic acid (TCA) and trichloroethylene (TCE) were investigated and reported (Susilawati et al., 2004; Saion and Mohd Asri, 2005, 2006, Susilawati, 2005, Mohd Asri and Saion, 2006). The mechanism by which radiation interacts with the dosimeters is by cleaving C-Cl bond of organic compounds followed by chemical reactions to increase the C=C bond of the indicator structure.

Upon irradiation, hydrogen and hydroxyl ions are formed as a result of dissociation of water molecules by radiolysis. Chlorine ions are also present due to radiation bond scission of chloral hydrate by dechlorination process. The recombination of hydrogen and chlorine ions produces hydrochloric acid which reacts with the base formed indicator to acid formed indicator resulting in colour change. The mechanism of the dosimeter operation can be understood by the following equations:

Irradiation: $H_2O \xrightarrow{\gamma\text{–rays}} H^+ + OH^-$ (radiolysis)

$RCl_3 \xrightarrow{\gamma\text{–rays}} RCl_2^+ + Cl^-$ (dechlorination)

Recombination: $H^+ + Cl^- \longrightarrow HCl$ (acidic condition)

Acid Formation: $In^- + H^+ \longrightarrow H\,In$ (colour change)

where In^- is the base form indicator and In is the acid form indicator. It has been observed that the formation of acid and C=C double bond increases with the increase of dose (Saion et al., 2004 a, Saion et al., 2004 b). The concentration of C=C bond increased corresponding to the increase of dose and thus, the hues of red colour. The useful colour change occurs at dose range 4 - 8 kGy, indicating that the film dosimeters are suitable as high dose dosimeters in irradiation facilities for food preservation. At this dose range spoilage and pathogenic microbes can be destroyed and improve shelf-life of meat, poultry, and seafood.

3D-Polymer Gel Dosimeters

Three-dimensional (3D) dosimeter is very important in radiotherapy treatment planning to image the dose distribution of radiation beams prior to the actual radiotherapy treatment for cancer (Maryanski et al., 1993). In resent years dosimetry based on magnetic resonance imaging (MRI) of polymer gels has become a diagnostic tool which allows high special-resolution 3D dose distribution to be imaged. The 3D dosimeters consist of a monomer (<6%) such as acrylamide, vinylpyrrolidone, and acrylic acid, a cross-linker (<6%) such as methylene-bis-acrylamide, and gelatin, water and anti-oxygen to complete the ingredients. The use of gelatin (<5%) and water is to simulate tissue equivalent (TE) characteristics of the human body. For some normoxic polymer gels prepared without purging nitrogen,

an anti-oxidant such as ascorbic acid may be added (Deene et al., 2002). The dosimeter is placed inside a phantom and irradiated with γ-rays of few Gy from several directions to simulate the actual radiotherapy treatment.

Upon irradiation, the monomer and cross-linker copolymerized and crosslinked into higher molecular mass polymer, in which the density is a function of absorbed dose. The newly formed insoluble polymer is spatially retained in the gelatin matrix that allows a complex dose distribution to be visualized in 3D by MRI or X-ray computed tomography. The mechanism by which copolymerization occurs in the polymer gel dosimeter is summarized by the following equations:

Irradiation: $2H_2O \xrightarrow{\gamma\text{–rays}} H^{\cdot} + OH^{\cdot} + H^{+} + OH^{-}$ (radiolysis)

$RH + OH^{\cdot} \longrightarrow R^{\cdot} + H_2O$ (radicals formation)

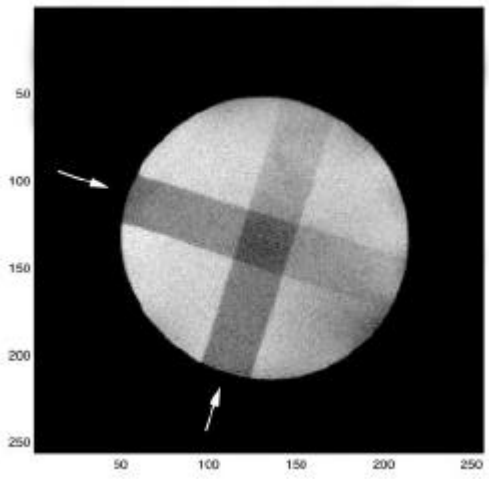
$RH + H^{\cdot} \longrightarrow R^{\cdot} + H_2$ (radicals formation)

Initiation: $R^{\cdot} + M_1 \longrightarrow RM_1^{\cdot} \longrightarrow RM^{\cdot}$ (copolymerization)

$R^{\cdot} + M_2 \longrightarrow RM_2^{\cdot} \longrightarrow RM^{\cdot}$ (copolymerization)

Propagation: $RM^{\cdot} + nM \longrightarrow R(M^{\cdot})_{n+1}$ (growing copolymerization)

Termination: $R(M^{\cdot})_{n+1} + R(M^{\cdot})_{m+1} \longrightarrow R(M)_{n+m}$ (polymer gels)



Polymer gel dosimeter

In this work, several monomers were used including acrylamide (Doyan et al., 2002, 2004, Doyan, 2005, Saion et al., 2005), methacrylamide (Doyan, 2005, Saion et al., 2006), hydroxyethylacrylate, hydroxyethylmethacrylate (Rabaeh et al., 2006, Rabaeh, 2007, Saion et al, 2007), and acrylic acid (Iskandar et al., 2006).

RADIATION GAUGING

Effective atomic number and electron density of compounds

The concept of effective atomic number is not valid over a wide range of gamma ray energies (Jackson, 1982). However, over limited ranges of low energy gamma rays it is an important quantity which can be used in diagnostic study to analyse the atomic composition of compounds. The effective atomic number may be defined as

$$\overline{Z} = \left(\sum_i a_i Z_i^{n-1}\right)^{\frac{1}{n-1}}$$

where α_i is the relative electron fraction of element i.

Following gamma interaction processes of photoelectric absorption, Compton scattering and Rayleigh scattering and pair production, the transmission photon beam intensity I is attenuated in accordance with $I = I_0 \exp(-mx)$, where I_0 is the incident beam intensity, x is the absorber thickness and μ is the linear attenuation coefficient. For a compound material, the linear attenuation coefficient is related to its atomic compositions given by

$$m(Z,E) = \sum_i s_i(Z,E)N_i$$

where s_i is the atomic cross-section for removal photons of energy E from the beam by atom type i, N_i is the number of atoms of type i per unit volume, and Z is the atomic number. At photon energy $E <$ 100 keV, the attenuation coefficient has been determined from nuclear data to be

$$m(E) = 28.44E^{-3.30}\overline{Z}^{4.47}\overline{N} + s_e(E)\overline{Z}\overline{N} + 3.18E^{-1.78}\overline{Z}^{2.50}\overline{N}$$

where $s_e(E)$ is Klein-Nishina cross-section for Compton scattering. This multi-interaction method has been used to determine the effective atomic number and electron density of rubber compounds.

The linear attenuation coefficients of the rubber samples were determined by the transmission attenuation method at energies 17.7 keV, 26.4 keV and 59.5 keV from 241 Am source using Si(Li) solid state detector. Solving three equations from three energy measurements, the effective atomic number $\overline{Z}$ and electron density $\overline{N}$ may be calculated. The effective atomic number of natural

rubber was found to be 4.99. Since the major elemental compositions of natural rubber are carbon and hydrogen, the effective atomic number is expected to be less than that of the carbon atom (Z=6). For sulphur vulcanised rubber compounds with carbon contents of 25, 50, and 75%, the effective atomic numbers were 8.06, 7.05 and 6.62 respectively (Saion et al., 1983) and their electron densities were 9.1×10^{22}, 1.0×10^{23} and 1.28×10^{23} respectively. For peroxide rubber compounds with carbon contents of 25, 50 and 75% the measured effective atomic numbers were 3.67, 4.08 and 5.52 respectively (Saion et al., 1994). It can be concluded that the effective atomic number and electron density of compound materials depend on the elemental compositions present in the materials.

Determination of DRC

Gamma ray attenuation technique has been used in multiphase systems such as the Hevea rubber latex. Consider Hevea latex as a mixture consisting of many components distributed uniformly throughout irradiated volume, then the attenuation of the mixture could be employed as $\mu_{mix} = (N_0/A)\,\sigma\,\rho_{mix}$, where the density of latex is given by $\rho_{mix} = \sum_i a_i\,\rho_i$ with a_i as the fraction of the total volume occupied by the i-th component of density ρ_i. Thus, the attenuation of the latex is

$$\mu_{mix}(E) = \sum_i a_i\,\mu_i(E)$$

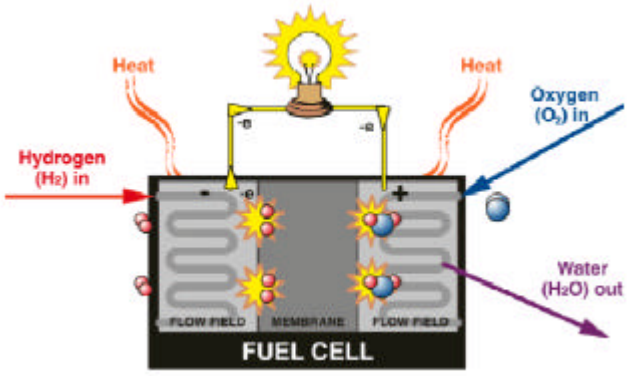
where μ_i is the linear attenuation coefficient of component i. This multi-component method has been used to determine dry rubber content (DRC) of Hevea latex.

The experimental set up is in accordance with the relation $I = I_0 \exp(-\mu x)$. In the case of Hevea latex the components were assumed as water and solid rubber (rubber and non-rubber solid).

The fractions of α_1 and α_2 were determined using two low energies of photon 17.7 keV and 26.4 keV that give the attenuation, which is mainly due to photoelectric absorption and Compton scattering. The correlation coefficient of 0.998 was achieved between the actual DRC determined by the standard method and the DRC measured by the attenuation technique (Saion et al., 1986).

RADIATION PROCESSING

Grafting of Ionic Exchange Membranes



The fuel cell is an electrochemical device that continuously converts the chemical energy of a fuel such as hydrogen and methanol directly into electricity without internal combustion. Low temperature hydrogen and direct methanol fuel cells have gained popularity because of their mobile and remote applications such as in laptop computers, cellular phones, digital cameras, and medical appliances. The polymer electrolyte membrane (PEM) is the vital component of a fuel cell system and it should possess hydrophilic properties, mechanical strength, good proton conductivity for high current densities, thermal and chemical stability for long life and stand temperature operation of about 150 °C.

Several commercial membranes like Nafion®, Flemion®, Aciplex® and Dow Chemicals are very expensive (USD 800 per m^2). An alternative PEM such as poly(ethylene-alt-tetrafluoroethylene) (ETFE), poly(tetrafluoroethylene) (PTFE) and polyvinylidene fluoride (PVDF) are said to have the hydrophilic properties equivalent to that of commercial membranes but at a much cheaper price of USD 50 per m2. ETFE occupies a special position among fluoropolymers as it contains alternating structural units of polyethylene (PE) and PTFE that offers unique combinations of property in terms of mechanical strength, thermal stability and superior resistance to common solvents and fatigue. It makes a suitable candidate for PEM, but after modification by grafting and sulfonation with SO_3^- or COO^- cationic group.

Among the various methods for initiating the grafting, such as chemical treatment and photo-irradiation, radiation technique is the cleanest and most versatile method of grafting available. It can be done by direct (mutual) or pre-irradiation radiation method, in which the latter does not produce homopolymer. In mutual grafting method the desired components such as the base polymer, the vinyl monomer and the solvent are irradiated simultaneously. By selecting a suitable solvent such as dichloromethane, which produces no homopolymer, mutual grafting of polystyrene onto base polymers can be achieved. In the pre-irradiation technique, there is no formation of homopolymer, yet the degree of grafting remains at lower limits (Nasef, 2002; Nasef and Saidi, 2003).

Upon irradiation the activated radicals formed on the base polymer and induced styrene copolymerization by interacting on its double bond of vinyl group ($-CH_2=CH_2$) to form activated polystyrene radicals, which then propagate and the grafting terminated by the solvent molecule to form polymer-g-polystyrene. The mechanism of mutual radiation technique can be understood by the following equations:

Irradiation: $P_A \longrightarrow P_A^{\cdot}$ (radiation processing)

Initiation: $P_A^{\cdot} + M_B \longrightarrow P_A M_B^{\cdot}$ (grafting)

Propagation: $P_A M_B^{\cdot} + nM_B \longrightarrow P_A (M_B^{\cdot})_{n+1}$ (polymerization)

Termination: $P_A(M_B^{\cdot})_{n+1} + mM_B \dashrightarrow P_A(M_B)_{n+m}$ (dead polymer)

where P_A and M_B are the base polymer and the monomer styrene respectively.

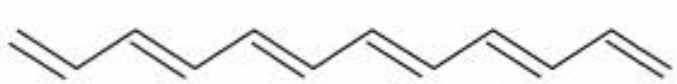
In this work, in order to achieve the optimal degree of grafting (DOG) various conditions including radiation dose, monomer concentration and type of solvent were investigated. Solvents such as dichloromethane, toluene and methanol were used in mutual grafting of polystyrene onto ETFE, PTFE and PVDF base polymers to form ETFE-g-polystyrene, PTFE-g-polystyrene and PVDF-g-polystyrene respectively (Yousuf, 2007). The sulfonation was achieved chemically in which the grafted films are attached with sulfonic acid (SO_3) group from the mixture of chlorosulfonic acid and tetrachloroethane. The analysis is in terms of various parameters such as degree of sulfonation (DOS), ionic exchange capacity (IEC), polystyrene content (PC), and sulfonic content (SC).

Our finding in this work is of high significance because for the first time the linear relationships between DOS and DOG (or between SC and PC) and between IEC and DOS (or between IEC and SC) were theoretically and experimentally established (Saion et al., 2007). Further, the DOS or SC per unit mass of sulfonated polystyrene is about 55% and independent of base polymer.

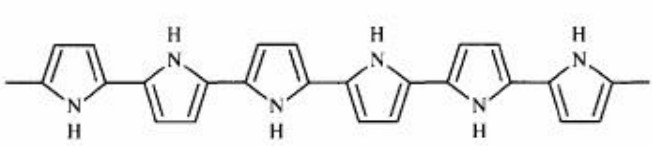
Polymerization of Conducting Polymers

Many years ago polymers or plastics were regarded as insulators and a remark that plastics can conduct electricity would have been considered as absurd. Indeed, plastics have been intensively used in industry because of their insulating property. It was only in 1967, that a postgraduate student of Hideki Shirakawa encountered, by mistake, the conjugated polymer of polyacetylene. The discovery of conducting polyacetylene was continued by Shirakawa, MacDiarmid and Heeger (Heeger, 1986) and for this they were awarded the Nobel Prize in 2000.

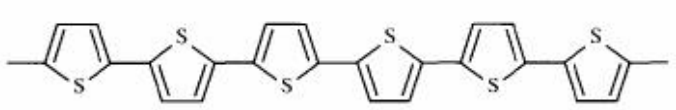
Conjugated polymers have a framework of alternating single and double carbon-carbon (sometimes carbon-nitrogen) bonds along the polymer chain. The electrical conductivities of the intrinsically conducting polymers range from those typical of insulators (10^{-10} S/cm) to those typical of conductors (10^{5} S/cm). The concepts of electrons (n-type) and hole (p-type) are the dominant charge carriers of semiconductors. However, in conducting polymers the concepts of solitrons, polarons and bipolarons are the dominant electronic charged carriers (Heeger, 1985). Polyacetylene is the simplest type of conducting polymer having solitrons as the charge carriers. The other conducting polymers are polypyrrole, polythiophene, polyaniline and polyphenylene, all of which possess polarons and bipolarons as charge carriers. The molecular structures of some conducting polymers are shown below



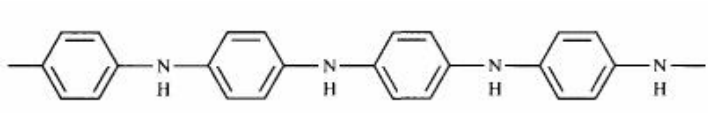
Polyacetylene



Polypyrrole



Polythiophine



Polyaniline

Molecular structure of various conducting polymers

Polymerization of conducting polymers is normally achieved by chemical reaction in the presence of monomers, an oxidizing agent, a dopant and a solvent (Ran et al., 2000; Rao et al., 2000). The electrochemical doping was discovered by MacDiarmid and Heeger in 1980s and hence it opens a new trend of synthesis of conducting polymers (Gurunathan et al., 1999). It is rapidly becoming the most preferred method because of its simplicity, reproducibility and controllable thickness and sizes. Sevil et al. (2000) has successfully prepared polyaniline/polyvinyl chloride (PVC) composites using UV-irradiation. Polyaniline composites prepared by chemical method have been irradiated to increase the conductivity (Wolszczak et al., 1996 a, b). Despite many published articles on conducting polymers, articles concerning polymerization of conducting polymers directly using ionizing radiation techniques are not available.

For the first time conducting polyaniline and polypyrrole composites have been synthesized by radiation doping (Hamzah et al., 2004, Azian et al., 2005, Saion et al., 2007, Mohammed, 2007). The polyaniline composite was prepared by irradiating films containing aniline hydrochloride as monomer and polyvinyl alcohol (PVA) as binder and gamma radiation as dopant. To prepare polypyrrole, pyrrole monomer was blended with chloral hydrate in PVA solution before caste and drying. The interaction of γ-rays with aniline hydrochloride ($C_6H_5NH_2.HCl$) or chloral hydrate results

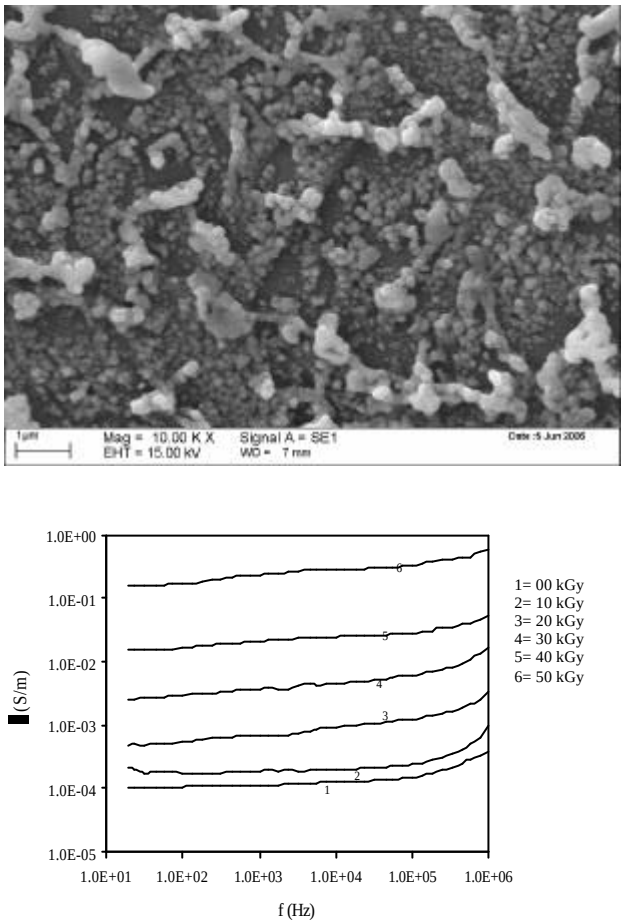
in the loss of Cl via dechlorination process. The chlorine acts as an oxidizing agent that dopes the amines group of aniline and in-situ polymerize into conductive polyaniline (polyemeraldin structure), which is green, the colour of polyaniline. For polypyrrole the colour is black. The possible reaction mechanisms may be written as

$$2_n C_6H_5NH_2.HCl \xrightarrow{\gamma} n[C_6H_5NH]\bullet\, n[C_6H_5HN^{+}\bullet\, Cl^{-}] + n\mathrm{HCl} + n\mathrm{H_2}$$
(polyaniline)

$$n[C_4H_4NH] + n[XCl_3] \xrightarrow{\gamma} n[C_4H_4NH^{+}Cl^{-}] + n[XHCl_2]$$
(polypyrrole)

X is an organic compound such as chloral hydrate, trichloroacetic acid and trichloroethylene. New compound $XHCl_2$ takes the ion H from PVA due to bond scission by gamma irradiation.

The SEM morphology reveals the formation of spherical aggregates of polyaniline nanoparticles. The formation of polyaniline has been followed by the formation of C=N double bond of imines group, representing the polarons and is in agreement with previous studies on chemical doping (Rao et al., 2000). The UV-vis absorption spectra of polyaniline at 790 nm produced the band gap of 1.01 eV at 50 kGy. It can be compared with the band gap of 0.83 eV for the Si semiconductor. The conductivity of the PVA/polyaniline nanocomposites increases by three orders of magnitude from $1.04\text{x}10^{-6}$S/cm at 0 Gy to $1017\text{x}10^{-5}$S/cm at 50 kGy (Saion et al., 2007). This can be compared to previous works where the values obtained were $4.8\text{x}10^{-4}$S/cm (Dutta et al., 2001) and $2.0\text{x}10^{-5}$S/cm (Cho et al., 2004) for PVA/polyaniline composites synthesized by chemical method.



Nanostructures and conductivity of PVA/polyaniline synthesized by radiation

Synthesis of Metal Nanoparticles

The intense scattering and absorption of light from metal nanoparticles such as silver and gold, is the source of the beautiful colors in stained glass windows and has attracted the interest of scientists for generations. The characteristic hues of these metal nanoparticle suspensions arise from the strong interaction of

conduction electrons with light. Metal nanoparticles exhibit a strong UV-vis absorption band that is not present in the spectrum of the bulk metal. The absorption band spectrum formed as a result of the incident photon frequency is resonant with the collective oscillation of the conduction electrons of metal nanoparticles and is known as the localized surface plasmon resonance (SPR). For surface plasmons to exist, the complex dielectric constants of the two media polymer/metal must be of opposite sign. Typical metals that support surface plasmons are silver and gold, but metals such as copper, titanium or chromium can also support surface plasmon generation (Aslan et al., 2005; Smith et al., 2003).

American physicist Richard Feyman once said at the American Physical Society Annual Meeting, Caltech, December 1959, "There's Plenty of room at the Bottom". It is partly because of his statement that many scientists are now looking at nano-scale dimensions. An understanding of the physical properties of metal nanoparticles holds both fundamental and practical significances. It is important to systematically explore the relationship between nanoscale material properties such as composition, size, shape and dielectric constant of surrounding dielectric materials that cause optical property variation. Practically, the tunable optical properties of nanostructures can be applied as materials for surface-enhanced spectroscopy, optical filters, plasmonic devices, sensors and catalysts.

A number of preparation techniques of polymer/metal nanoparticles have been reported such as chemical, photochemical, electrochemical and sonochemical reduction. Of these techniques, the radiation-induced synthesis has many advantages such as being a simple and clean process, no reducing agent or production of oxidation product, the metal nanoparticles is fully reduced, the particles are highly pure and stable and it produces no impurities. In radiation-induced reduction technique, the polymer/metal compound is exposed to γ-rays creating solvated electrons. These electrons in turn, reduce the metal ions and the metal atoms eventually coalesce

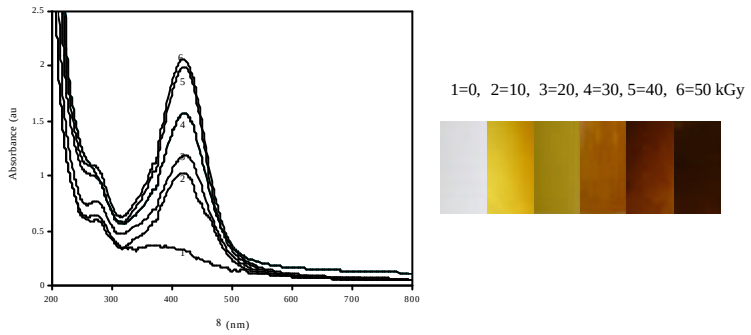
to form aggregates of nanoparticles. The mechanism of the radiation-induced reduction technique can be understood by the following equations:

Irradiation: $MX/Polymer \xrightarrow{\gamma\text{–ray}} MX + e^-/Polymer$ (radiation processing)

Reduction: $e^- + M^+ \longrightarrow M^0$ (atoms)

Aggregation: $nM^0 + M^0 \longrightarrow (n+1)M^0$ (nanoparticles)

In this work, silver nitrate $AgNO_3$ was used as the metal compound and mixed with PVA and PVA/aniline hydrochloride solution before casting and drying into films. No anti-oxidant was added. The films were irradiated at different doses of up to 50 kGy to increase the number of Ag nanoparticles formed (Mohammed, 2007). The colour of the films changed from colourless to yellow or golden yellow as the dose increased due to the reduction of Ag^+ to Ag^0. PVA acts as a binder or protective agent, which restricts the mobility of the Ag^+ during reduction and prevents aggregation among the Ag^0 particles, thus limiting the size of Ag^0 nanoparticles (Bogle et al., 2006; Khanna et al., 2005). Our results also indicate that as the dose increased, the SPR peak at 425 nm shifts towards lower wavelength, indicating smaller diameters of the Ag^0 nanoparticles produced at higher radiation doses. The band gap energy increased following the radiation dose increment from 2.54 eV at 10 kGy to 2.65 eV at 50 kGy (Mohammed et al., 2007). Such an increase in the band gap energy is attributed to the conduction band of surface plasmons which increases as the diameter of Ag^0 nanoparticle decreases.



Absorbance and colour of PVA/Ag^0 nanoparticles at different doses

CONCLUSIONS

This inaugural lecture conveys some of the fundamental aspects and important issues of ionizing radiation. In the social aspect we highlighted the sources of natural radiation that man is continuously exposed to and has adapted to without need for extra protection. The misunderstandings regarding the use of artificial radiation have been discussed such as the fact that food irradiation does not make food radioactive and that it makes food safe from pathogenic microbes. Ionizing radiation can cause physical, chemical, and biological effects, where the latter has been given special attention highlighting that the amount of dose determines the risk or possibility of death by cancer when exposed to accidental radiation. The risks over the population and the workplace have been compared and the fact established that the radiation risk is small when compared to other risks.

In environmental studies we emphasized on the application of nuclear activation analysis to monitor pollution levels. Its detection capability is impressive as shown by sensitivity of one part per billion (ppb) and capacity to analyse more than 40 different elements simultaneously. In the aspects of diagnostic and radiation protection,

it is important to develop devices for assessing biological damages and to use this to limit the dose of unnecessary radiation exposure. This lecture also drew attention to the physical principles and the chemical binding effects of ionizing radiation that are valuable in developing novel techniques for the synthesis of functional materials such as ionic exchange membranes, conducting polymers and metal nanoparticles. Overall, this lecture has brought to light the exciting applications of ionizing radiation in some areas of nuclear physics, atomic physics, radiation chemistry and molecular engineering.

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BIOGRAPHY

Dr Elias Saion is currently serving as a professor of Applied Radiation at Universiti Putra Malaysia (UPM). He was brought up in a village, 1.5 km from Tangkak, Johor, and had his primary education at Sekolah Kebangsaan Lelaki Bandar Tangkak and his secondary education at Sekolah Menengah Tangkak, Sekolah Dato Seri Amar DiRaja Muar and Sekolah Sultan Abdul Halim Jitra. He received his BSc in Physics from Universiti Kebangsaan Malaysia (UKM) in 1975. It was at UKM where he deepened his interest in the subjects of contemporary physics especially on atoms, nuclear, and particles. He became fascinated by ionizing radiations that originated from the atomic and nuclear structures and by what they could offer to mankind and to the environment. After getting a release from Johor state duty he joined Universiti Putra Malaysia (previously known as Universiti Pertanian Malaysia) (UPM) as a tutor in July 1975. He went to University of Surrey in 1976 where he obtained his MSc in Medical Physics in 1978. He was then appointed as a lecturer in late 1978. After serving as lecturer for several years, he continued his study at St Andrews University in 1985 and obtained his PhD in Radiation Biophysics in 1989. He was appointed as an Associate Professor in 1996. Since then, he

has held three administrative positions at UPM including as the Director and the Deputy Director of the Centre of Matriculation Studies (1996 - 2000) and as the Deputy Director of the Centre of General Studies (2000 - 2001). After a break from administration duties he concentrated on his research and was appointed as a full professor of Applied Radiation in 2006. At present he holds the post as Head of the Physics Department until the 1st June 2008.

He and his colleagues have secured a number of research grants through the Intensification of Research in Priority Area (IRPA) and Science Fund from the Ministry of Science and Technology (MOSTI), the Fundamental Grant from the Ministry of Higher Education and the Research University Grant (RUGS) from Universiti Putra Malaysia. Currently, he is the group leader in the applied radiation and nanosciences groups. Professor Elias Saion's research activities have been primarily concerned with interactions of ionizing radiation with matter including sediment samples for the environment, polymer gel dosimeters for radiotherapy treatment planning, radiation synthesis of ionic and conducting polymers for electrochemical devices, radiation grafting polymer membranes for fuel cells and radiation synthesis of metal and metallic oxide nanoparticles for sensors and catalysts. Most of his research involve radiation interactions that cause ionization, radicals, and bond scission, and subsequent chemical effects such as polymerization, copolymerization, crosslinking and grafting. He also served as co-researcher in some other research areas in materials sciences and alternative energy. He has received scientific awards for his group research notably several gold, silver and bronze medals in invention/ innovation and research exhibitions at the university and at the national level. The awards consist of medals and inscribed certificates.

Besides being engrossed in research, he enjoys imparting knowledge and experience to postgraduate students from within the country and from different nationalities including Saudi Arabia,

Jordan, Indonesia, Iran, Iraq, Pakistan, Sudan and Yemen. Currently, he is the principal supervisor of postgraduate students (6 PhD and 5 MSc) and he has previously been the principal supervisor to 6 PhD and 8 MSc students. He is the author and co-author of numerous journal articles, proceedings of conferences, seminars, reports and bulletins (over 200 articles) on the subjects of applied radiation and materials science. He is also the author and co-author of physics books (7 books) and chapters in physics books (9 chapters). He has served as invited speaker, speaker, poster presenter, and session chairman at international and national conferences and seminars. He has also served as referee for scientific journals at the national and international levels. He is a member of several local and international professional bodies on physics related fields. Currently, he is a Fellow of the Malaysian Solid State Science and Technology Society (MASS). He has headed several curriculum committees at various levels, including pre-university, undergraduate, and postgraduate levels. He is the co-chairman of the physics curriculum committee for the Ministry of Education's matriculation program, the head of curriculum committee of the pre-university program of MSN-KPTM-UPM-UTM, a member of Science Faculty curriculum and postgraduate committees and was previously a member of the UPM curriculum committee. He has also been chief consultant for two private institutions (UNITEN and PETRONAS) in curriculum design and implementation during the early years of their academic programs.

LIST OF INAUGURAL LECTURES

1. Prof. Dr. Sulaiman M. Yassin
   The Challenge to Communication Research in Extension
   22 July 1989

2. Prof. Ir. Abang Abdullah Abang Ali
   Indigenous Materials and Technology for Low Cost Housing
   30 August 1990

3. Prof. Dr. Abdul Rahman Abdul Razak
   Plant Parasitic Nematodes, Lesser Known Pests of Agricultural Crops
   30 January 1993

4. Prof. Dr. Mohamed Suleiman
   Numerical Solution of Ordinary Differential Equations: A Historical Perspective
   11 December 1993

5. Prof. Dr. Mohd. Ariff Hussein
   *Changing Roles of Agricultural Econ*omics
   5 March 1994

6. Prof. Dr. Mohd. Ismail Ahmad
   Marketing Management: Prospects and Challenges for Agriculture
   6 April 1994

7. Prof. Dr. Mohamed Mahyuddin Mohd. Dahan
   The Changing Demand for Livestock Products
   20 April 1994

8. Prof. Dr. Ruth Kiew
   Plant Taxonomy, Biodiversity and Conservation
   11 May 1994

9. Prof. Ir. Dr. Mohd. Zohadie Bardaie
   Engineering Technological Developments Propelling Agriculture into the 21st
   Century
   28 May 1994

10. Prof. Dr. Shamsuddin Jusop
    Rock, Mineral and Soil
    18 June 1994

11. Prof. Dr. Abdul Salam Abdullah
    Natural Toxicants Affecting Animal Health and Production
    29 June 1994

12. Prof. Dr. Mohd. Yusof Hussein
    Pest Control: A Challenge in Applied Ecology
    9 July 1994

13. Prof. Dr. Kapt. Mohd. Ibrahim Haji Mohamed
    Managing Challenges in Fisheries Development through Science and Technology
    23 July 1994

14. Prof. Dr. Hj. Amat Juhari Moain
    Sejarah Keagungan Bahasa Melayu
    6 Ogos 1994

15. Prof. Dr. Law Ah Theem
    Oil Pollution in the Malaysian Seas
    24 September 1994

16. Prof. Dr. Md. Nordin Hj. Lajis
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