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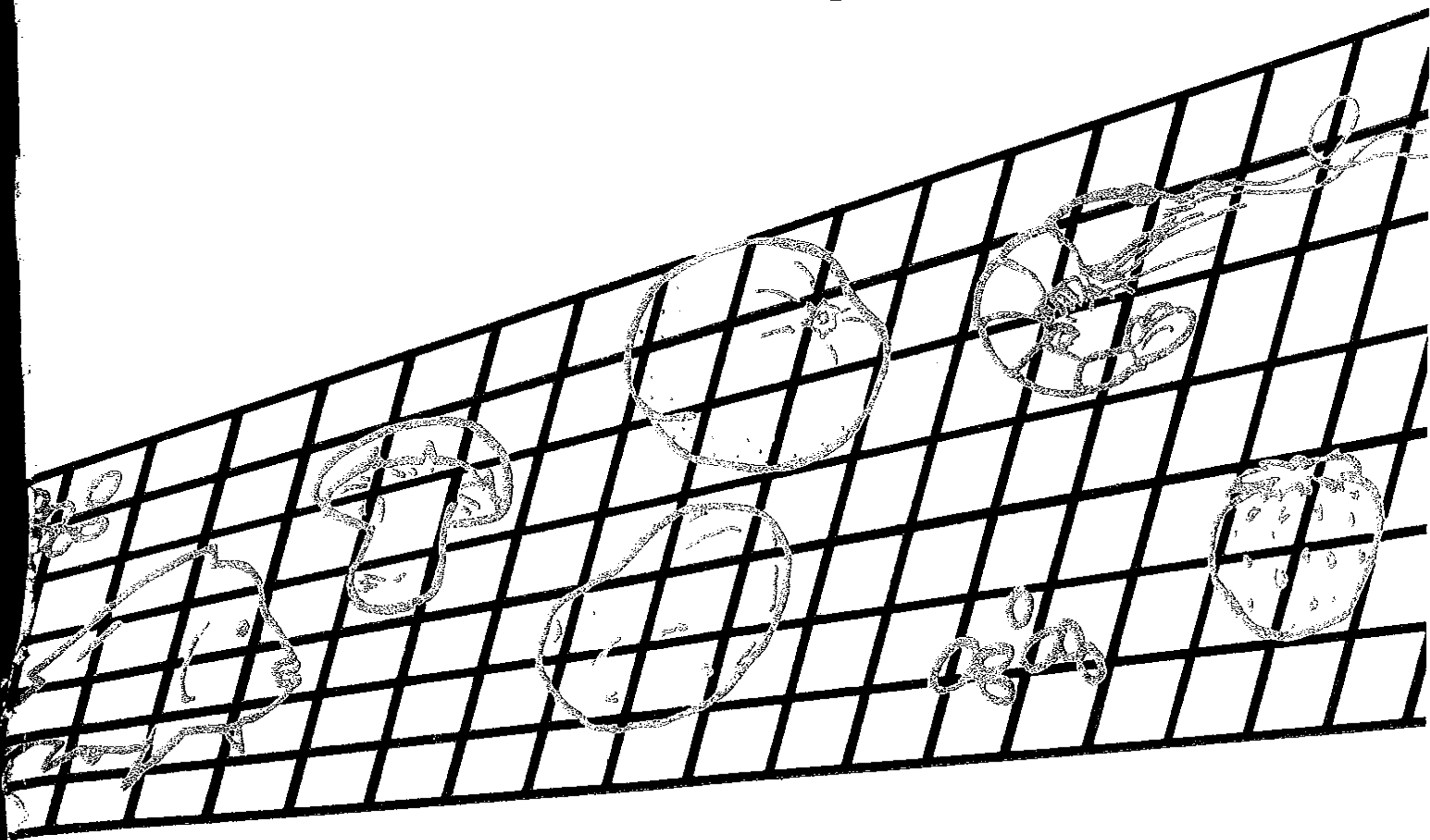
INTERNATIONAL ATOMIC ENERGY AGENCY REGIONAL WORKSHOP

COMMERCIALISATION OF IONISING ENERGY TREATMENT OF FOOD

29 APRIL TO 10 MAY, 1985
LUCAS HEIGHTS, NEW SOUTH WALES, AUSTRALIA

PROCEEDINGS



HOSTED BY
AUSTRALIAN ATOMIC ENERGY COMMISSION IN CO-OPERATION WITH
INTERNATIONAL ATOMIC ENERGY AGENCY

CO-ORDINATED BY AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

INTERNATIONAL ATOMIC ENERGY AGENCY

REGIONAL WORKSHOP ON

COMMERCIALISATION OF IONISING ENERGY TREATMENT OF FOOD

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PROCEEDINGS

PAMELA WILLS
Australian Atomic Energy Commission
Workshop Director

PAISAN LOAHARANU
Joint FAO/IAEA Division of Isotope and Radiation
Applications of Atomic Energy for Food and
Agricultural Developments
IAEA
Vienna, Austria

BERNARD TONER
Australian School of Nuclear Technology
Workshop Co-ordinator

FOREWORD

The global need to ensure adequate food supplies places a demand on new technologies and techniques to improve yields and preservation of food by eliminating or reducing bacterial degradation and infestation of raw or processed foods.

The use of ionising radiation in food processing also has potential to alleviate certain food-borne diseases which cause serious threats to the health of people in many countries.

The Australian Government through the Australian Atomic Energy Commission is pleased to undertake the lead role over the next three years by providing funds for Phase II of the Regional Cooperative Agreement to assist in accelerating the establishment of the food irradiation process on a commercial basis.

Australia with its research interest in the food irradiation process over the past 25 years was prepared to assemble its National experts to present the Workshop as the initial event of the Phase II program to support the transfer of the technology within the Region. The Workshop was viewed as a highlight of the Atomic Energy Commission's support for the peaceful application of nuclear research and technology in the Region.

I wish to thank all the AAEC staff of the Isotope Division who provided a major part of the effort in presenting the Workshop and the expert lecturers from outside the AAEC who willingly gave their time to ensure the success of the Workshop.

My thanks also to the Australian School of Nuclear Technology for their role in acting as Workshop Coordinator.

I am confident that these proceedings of the Workshop will be a real contribution to support the commercialisation of the process and bring considerable benefit to a number of member countries in the Region.

D.G. WALKER
Commissioner and Chief Executive
Australian Atomic Energy Commission
Sydney Australia - July, 1985

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AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

WORKSHOP ON COMMERCIALISATION OF IONISING ENERGY TREATMENTS OF FOOD

29 April to 10 May, 1985

LIST OF PARTICIPANTS

Dr. Rodney FARR-WHARTON	Senior Technical Officer, Alcan Foil Products, Cabramatta, NSW
Mr. Chris DAHM	Process Research Officer, Uncle Ben's of Australia, Wodonga, Vic.
Mr. Derek SNOWBALL	Engineer, Turners & Growers Ltd., Auckland, New Zealand
Mr. David PANASIAK	Food Technologist, Commonwealth Dept. of Health, Woden, ACT
Mr. Gregory MITCHELL	Senior Chemist, Department of Primary Industry, Hamilton, Queensland
Mr. Tim EDGECOMBE (part time)	Engineer, Committee of Direction of Fruit Marketing, Brisbane Markets, Queensland
Mr. John HOLTON	Senior Agriculture Quarantine Officer, Ministry of Agriculture & Fisheries, Auckland, New Zealand
Mr. Neil HEATHER	Department of Primary Industry, Hamilton, Queensland
Mr. Kovit NOUCHPRAMOOL	(Scientist), Office of Atomic Energy for Peace, Thailand
Mrs. Carmen SINGSON	(Scientist), PAEC, Dept. of Nuclear Services, Philippines
Mr. Muhamad bin LEBAI JURI	(Scientist), Nuclear Energy Unit, Prime Ministers Department, Malaysia
Mrs. Bunya SUDAITIS	Government Official, Atomic Energy for Peace, Thailand.
Ms Brenda RIVERA	(Industrialist), Director for Corporate Planning Dept., Food Terminal Inc, Philippines
* Dr. M.M. HOSSAIN	(Scientist), Member, Bio-Science BAEC, Bangladesh
* Ms Munsiah MAHA	(Scientist), Centre for Application of Isotopes & Radiation, Indonesia
* Dr. Han-Ok CHO	(Scientist), Radiation Application Dept., KAERI, Republic of Korea
* Mr. Aslam MALIK	(Scientist), Atomic Energy Commission, Pakistan
Mr. Fred METSELAAR (part time)	Pilon Plastics, St. Peters, NSW

* Attended RPFI Project Committee Meeting from 13-16 May, 1985

AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

IAEA/RCA ASIAN REGIONAL PROJECT ON FOOD IRRADIATION
WORKSHOP ON COMMERCIALISATION OF IONISING ENERGY TREATMENTS OF FOOD (IETF)

WEEK 1

TIME	MONDAY 29 APRIL	TUESDAY 30 APRIL	WEDNESDAY 1 MAY	THURSDAY 2 MAY	FRIDAY 3 MAY
9.00	INTRODUCTION B. Toner, D.G. Walker, C. Hardy, P. Loaharanu Basic Nuclear Physics D. Culley (ASNT) Recent Developments P. Loaharanu (IAEA) Removing Off-flavours with IET D. Freeman (AAEC)	FRUIT AND VEGETABLES Post-harvest Storage, Problems N. Wade (NSW Dept. Agric. North Ryde) Treatment of Fruit C. Rigney (Post-Harvest Laboratory, Gosford) Treatment of Vegetables S. Morris (Post-Harvest Laboratory)	FUNDAMENTALS Radiation Chemistry P.W. Moore (AAEC) Radiation Microbiology P.A. Wills (AAEC) Radiation Entomology E. Shipp (UNSW)	CEREALS, PULSES, SPICES Post-harvest Storage, Problems D. Evans (CSIRO, Canberra) Treatment of Cereals M. Wootton (UNSW) Treatment of Spices C. Saul (McCormicks, Melb)	MEAT AND POULTRY Meat Storage, Spoilage L. Brownlie (AMLC Sydney) Treatment of Meat A. Egan (CSIRO, Brisbane) Treatment of Poultry R. Proudford (HAC)
12.00		PANEL DISCUSSIONS			
13.00	L	U	N	C	H
14.00	Radiation Protection J. Button (AAEC) Gatri Familiarisation M.E. Izard (AAEC) Radiation Dosimetry M.E. Izard (AAEC)	GATRI TRIALS Fruit Vegetables	QUARANTINE WITH IMPORTS & EXPORTS J. Turpin, R.S. Pinson, G.M. Higgs, B.J. Read) NSW Dept. Agric.	GATRI TRIALS Stored Products Cereals, Spices	VISIT Commercial Accelerator - St. Peters
17.30	RECEPTION Lucas Heights				

AAEC - Australian Atomic Energy Commission
ASNT - Australian School of Nuclear Technology
AMLC - Australian Meat and Livestock Corporation
ACA - Australian Consumer Association
CSIRO - Commonwealth Scientific and Industrial Research Organization, North Ryde - Division of Food Research
Brisbane - Division of Food Research, Meat Research
Hobart - Division of Food Research, Fishery Products
Canberra - Division of Entomology

UNSW - University of New South Wales
HAC - Hawkesbury Agricultural College
DPI - Department of Primary Industry
QDPI - Q'land Dept. Primary Industries

AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

IAEA/RCA ASIAN REGIONAL PROJECT ON FOOD IRRADIATION
WORKSHOP ON COMMERCIALISATION OF IONISING ENERGY TREATMENTS OF FOOD (IETF)

WEEK 2

TIME	MONDAY 6 MAY	TUESDAY 7 MAY	WEDNESDAY 8 MAY	THURSDAY 9 MAY	FRIDAY 10 MAY
9.00	FISHERY PRODUCTS Storage and Spoilage S.I. Thrower (CSIRO Hobart) Public Health Problems M. Eyles (CSIRO, Nth Ryde) Treatment of Fish P. Loaharanu (IAEA)	IRRADIATION FACILITIES Machines: (i) >2 MeV J.G. Clouston (UNSW) (ii) <2 MeV J.R. Bird (AAEC) Isotope Sources: ^{60}Co G. West (Ansell, Melb.) Cost Analysis R. Culpitt (QDPI)	MARKETING STRATEGIES PANEL International B. Carone (Amatil, Sydney) Consumers C. Campbell (ACA) Education J. Taylor (Q'land Consumer Affairs) Supermarkets R. Clairs (Woolworths)	REGULATORY ASPECTS CAC Standard and COP L. Erwin (DPI, Canberra) Facilities A. Fleishchmann (NSW Dept. of Health) RCA Region Requirements Participants	PACKAGING Principles D. Hartley (Arnotts) Aseptic Filling (liquids) I. Anderson (Wrightcell) Display Treatment of Materials P.W. Moore (AAEC)
12.00		PANEL DISCUSSIONS			
13.00	L	U	N	C	H
14.00	GATRI TRIALS Meat Poultry Seafoods	VISIT Industrial ^{60}Co Plant Wetherill Park G. West (Ansell)	GATRI TRIAL RESULTS Fruit and Vegetables Stored Products Meat, poultry, seafoods	VISIT CSIRO, Food Research Labs. North Ryde Organoleptic Tests R. McBride (CSIRO)	REVIEW OF WORKSHOP
19.00	OFFICIAL RECEPTION Sky Room Restaurant Miranda				

THE AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

A co-operative enterprise of
The University of New South Wales and
The Australian Atomic Energy Commission

This is to certify that

attended a workshop on

COMMERCIALISATION OF IONISING ENERGY TREATMENTS OF FOOD

as part of the IAEA/RCA Asian Regional Project
on Food Irradiation

Hosted by

THE AUSTRALIAN ATOMIC ENERGY COMMISSION
Lucas Heights, N.S.W.

which was presented between 29 April and 10 May, 1985

PAMELA WILLS
Senior Principal Research Scientist
AAEC
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BERNARD TONER
Principal
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Agricultural Development
IAEA
Vienna Austria

LECTURE 1

BASIC NUCLEAR PHYSICS

D. CULLEY

AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

BASIC NUCLEAR PHYSICS

D. Culley

1.0 ATOMIC STRUCTURE

The atom consists of a small dense nucleus, which contains over 99.97% of the atom's mass surrounded by a cloud of electrons (Figure 1). The radius of the nucleus is about 6×10^{-13}cm or 6 femtometres, and that of the atom 10^{-8}cm or 0.1 nanometres. In other words, the radius of the atom is 17,000 times that of the nucleus and its volume 5×10^{12} times greater.

The electrons, whilst orbiting the nucleus, actually exist in discrete energy states. In these states, unlike the circular orbits of classical electrodynamics, no energy is lost, or gained, by the electron whilst in the orbit. A change of energy of an electron only occurs when it changes its energy state. The great majority of the mass of the atom resides in the nucleus which, itself, is composed of neutrons and protons. These particles are known as NUCLEONS. They have approximately the same weight - one ATOMIC MASS UNIT (amu) the symbol for which is 'u' and the actual mass of which is 1.66×10^{-24} gm. The mass of the proton is 1,822 times that of the electron.

The value of the electric charge on both particles is 1.6×10^{-19} Coulomb. The charge on the proton is positive and on the electron is negative. The neutron has zero net charge but it is thought to have a distribution of charge across its radius.

The density of nuclear matter is about 10^{8} tonnes per cubic centimetre.

2.0 IONISATION

If an electron is removed from, or added to, the outer electrons of an atom, that atom becomes electrically charged. In this state the atom is called an ION. Ionisation of atoms can be caused by a charged particle knocking the electron out of its orbit during its passage through that particular piece of matter. In a particle detector which uses a gas as the detecting medium, the charged particles form trials of ions which give rise to electrical signals from the detector signifying the passage through the detector of those particular particules.

In its ionised state an atom can be affected by both electrical and magnetic fields.

3.0 X-RAYS

These are a form of electromagnetic radiation as is light, radio, infra-red, ultra-violet and micro-waves. They were discovered by RÖENTGEN in 1895. The basic mechanism for their production is the change in the energy state of the electrons from higher to lower levels within the atom.

4.0 ENERGY

The energy of a particle is given in a unit known as the ELECTRON-VOLT, the abbreviation for which is eV. This is defined as the kinetic energy acquired by a particle carrying unit electric charge (positive or negative) when it moves through an electric potential of one volt. It can be shown that:

$$1\ \text{eV} = 1.6 \times 10^{-19}\ \text{Joule}$$

NOTE - This is a KINETIC ENERGY which is given by:

$$\text{K. E.} = \frac{1}{2} m v^2$$

and that the actual velocity of the particle will vary with its MASS. An electron will travel with a velocity approximately 85 times that of an Alpha-particle. For example at an energy of 1 eV, an electron has a velocity of 600 km/sec. and an Alpha-particle a velocity of only 3.5 km/sec.

From the equivalence of mass and Energy, as obtained in Einstein's Special Relativity Theory, we can show that one atomic mass unit is equivalent to 931.48 MILLION electron volts (MeV) and that the energy equivalent of an electron is 0.511 MeV.

5.0 NUCLEAR STRUCTURE

The number of protons in the nucleus gives the magnitude of its electrical charge - this is known as the ATOMIC NUMBER and is denoted by 'Z'. In the neutral atom the positive charge of the protons is balanced by that of the orbiting electrons. The chemical properties of the elements depend upon the number of electrons and hence upon the value of Z.

The mass of the nucleus is given, in atomic mass units, by the sum of the masses of the protons and neutrons. The actual ATOMIC MASS is denoted by 'M'. The ATOMIC MASS NUMBER, which is denoted by 'A' is the nearest integer to M. The number of neutrons is denoted by 'N'.

Some atoms of an element have differing numbers of neutrons in the nucleus. They are said to be ISOTOPES of that element. The chemical properties are the same but physical properties which are affected by the atom's weight, such as boiling point, melting point, rates of electrolytical dissociation and diffusion rates will differ. This property has been used in such processes as the separation of Heavy from Light water and the enrichment of natural Uranium in ^{235}U.

6.0 BETA-PARTICLES and POSITRONS

A radioactive nucleus has a certain amount of excess energy which must be dissipated. It can do this in any one of several ways which usually involve the emission of one, or more, particles. The most common, which will concern us here today, are the Beta-particle and the Gamma-ray.

The Beta-particle is actually a high speed electron. Its emission is explained by postulating the decay of a neutron, in the nucleus, into a proton and an electron.

$$n_o \longrightarrow p^+ + e^- + \nu$$

The loss of negative charge leads to an INCREASE, by one, in the value of Z.

Beta-particles are emitted with a range, or SPECTRUM, of energies (Figure 2). This phenomenon immediately suggests that, during the decay process, not one but two particles are emitted. WOLFGANG PAULI, in 1931, suggested that the maximum, or end-point, energy of a Beta-particle spectrum was equal to the disintegration energy. To account for the existence of the spectrum he hypothesised the existence of a third, neutral, particle. ENRICO FERMI postulated that such a particle was, not only neutral, but also weightless and chargeless with an extremely high velocity. He gave it the name NEUTRINO ("little neutron") in 1933. Since that time the neutrino has not only been detected but an estimate of its weight, or at least its energy equivalent, has been measured. For Beta-particles, it is usual to quote the maximum, or end-point, energy as being the typical energy for that particular decay.

When talking about the properties of the Beta-particle, it is also usual to consider those of the POSITRON. This particle is often called the ANTI-ELECTRON, as it is simply an electron with a POSITIVE instead of a negative charge. It has a similar energy distribution (Figure 3) to that of a Beta-particle and when it has lost all its energy by the ionisation process, it collides with an ordinary electron and both particles disappear in a blaze of mutual annihilation with the resultant production of two 0.511 MeV Gamma-rays. The loss of positive charge in the nucleus will lead to a DECREASE, by one, in the value of Z. It should be pointed out that a positron emitter is a strong source of 0.511 MeV Gamma-rays.

Beta-particles are light and very fast and their ionising capabilities are very small. As a consequence the ionising power of Beta-particles only gives rise to about 40 ion pairs per cm which means, for example, that a 3 MeV Beta-particle has a range, in air of about 10 metres. The basic interaction with matter is the collision of an electron with another electron and consequently the Beta-particle can be scattered through large angles on each collision. Hence its path may be rather tortuous with no well defined range but there is a maximum range. The variation of the range of Beta-particles, with energy, has been the subject of considerable study over the years and it is possible to determine the maximum energy of a Beta-particle by determining its range in a material - which is usually Aluminium. A typical absorption curve for a Beta-particle is shown in Figure 4. The 'tail' of the curve is due to Gamma-rays and it is possible to determine the range by extrapolation. Possibly the most detailed work on this topic was done by Katz and Penfold in 1952 (Data shown in Figure 5) but a fairly simple formula which may be used is due to Feather:-

$$R(\text{gm/sq.cm}) = 0.543E + 0.16$$

where E is the maximum energy of the Beta-particle emission. It should be noted here that, in absorption measurements, thickness is often given in units of mass per unit area (A surface density) - either grams or milligrams per square centimetre. Usually for Beta-particles the absorber is Aluminium. It has been found that, if the amount of absorber is expressed in this manner, then the range is nearly independent of the nature of the absorber.

7.0 GAMMA-RADIATION and NUCLEAR ENERGY LEVELS

When a nucleus is formed it is usually in an excited state and it goes to its unexcited, or GROUND state, by losing energy in the form of Gamma-radiation.

This is electro-magnetic radiation of very short wavelength, similar to radio-waves, infra-red, visible light, micro-waves and ultra-violet light. Gamma-rays cover the same wavelength range as X-rays but the difference lies in the origin of the radiation. X-rays originate from the change in the energy levels of the inner orbital electrons of the atom and Gamma-rays come from the nucleus.

In this decay there is no change in N, Z or A. By studying the Gamma-ray emissions of an excited nucleus we find that they have discrete energies. This phenomenon gave rise to the concept of nuclear energy levels, somewhat analogous to the discrete energy states of the electrons. A nucleus can exist in any one of a set of energy levels if it is excited. Each nucleus has a unique energy level scheme and it is possible to identify a nucleus from the Gamma-rays that it emits. There are rules, known as SELECTION rules, that govern the transitions between levels. It should be noted that for the lighter elements the levels are well separated, often by several MeV, at the lower energies near the ground state but that as the nuclei get heavier and the excitation energy gets larger then the levels get closer together.

A nucleus in an excited state may decay directly to the ground state, in which case the radiation is referred to as primary, or it may decay to another excited state and THEN to the ground state, in which case the second decay is referred to as secondary radiation. Figures 6 and 7 are the decay schemes for ^{60}Co and ^{137}Cs. ^{60}Co decays by Beta-particle emission with a halflife of 5.27 years to one of two levels of ^{60}Ni.

More than 99% go to the 2.5057 MeV level of the ^{60}Ni. The remaining fraction of a percent can be ignored.

From the 2.5057 MeV level ^{60}Ni decays by first emitting a 1.17323 MeV Gamma-ray to go to the 1.3325 MeV level and then emitting a further Gamma-ray of 1.3325 MeV to reach the ground state. ^{137}Cs, which is formed as a fission product, decays by Beta-particle emission to ^{137}Ba with a halflife of 30.1 years. 93.5% of emissions go to the 0.6616 MeV level of ^{137}Ba and the remaining 6.5% go to the ground state of the of the ^{137}Ba. The transition rules governing the decay from this excited state dictate that, unlike most transitions from excited states, this one is NOT instantaneous but is actually "forbidden". This effectively means that a radioactive form of ^{137}Ba is created which has a halflife of 2.55 minutes.

8.0 INTERACTION OF RADIATION WITH MATTER

8.1 Beat-particles and Fast Electrons

These particles lose their energy by ionisation collision with atomic electrons and bremsstrahlung production when the electron is deccelerated, rapidly, in the Coulomb field of the nucleus. Enerty loss generally predominates and increases with the value of Z for the absorber but is not affected by increase in the energy of the electron. Energy loss by bremsstrahlung increases as Z^2 for the absorber and with increase in electron energy. For example, for 1 MeV electrons stopped in lead, the ratio of energy loss by ionisation to loss by bremsstrahlung is 10 to 1 whereas for 10 MeV electrons it is close to one.

8.2 X and Gamma Radiation

The primary interaction of X and Gamma rays with matter involves the transfer of energy from the photons to individual electrons either by ionisation or by excitation of the atoms of the detecting medium. Those electrons which are set free can produce either further ionisation or excitation.

For energies up to a few MeV there are three main absorption processes which are of importance.

8.3 Photo-electric Absorption

This process involves a single collision between a photon and an INNER orbital electron (Figure 8) in which all of the energy of the photon is transferred to the electron which is ejected from the atom. The excited atom deexcites by emitting X-rays.

The probability for photo-electric absorption varies approximately as Z^4/E^3_γ so that this process is important for photons of low energy E_γ absorbed in materials of high atomic number Z.

8.4 Compton Scattering

In this process a photon makes a scattering collision with an outer electron (Figure 9) in which only part of its energy is transferred to the electron. The scattering electron will have its energy degraded by further encounters which will set free additional Compton electrons. The energy spectrum of the Compton electrons extends from zero to a maximum which is slightly below the primary photon energy. In light materials such as air and water this process is of major importance for primary photon energies from about 30 keV to 10 MeV.

8.5 Pair Production

In this process a high energy photon interacts directly with the Coulomb field of the nucleus (Figure 10) and is converted into an electron-positron pair. This process cannot occur unless the photon energy is at least equal to the rest mass energy of the two particles (1.02 MeV). Excess energy above this amount is shared equally. The electron-positron pair dissipate their energy by ionisation collisions until they come to rest when the positron combines with an ordinary electron to produce two 0.51 MeV annihilation photons. This process is of importance for high energy photons absorbed in materials of high atomic number.

It is obvious from the above that all three processes can occur at the same time, if the photon energy is greater than 1.02 MeV but that their relative importance will vary widely with energy and Z value for the absorber. The probabilities of absorption are expressed as coefficients in units of cm squared per gm. The curves for the absorption coefficients for Aluminium and Lead are shown in Figure 11 and the curve for Sodium Iodide is shown in Figure 12.

9.0 INDUCED RADIOACTIVITY BY BETA-PARTICLES and GAMMA-RAYS

Generally this is not a problem as the conditions for absorption of Beta-particles by nuclei are so specialised and the probabilities so small that the chance of capture is vanishingly small.

For Gamma-rays capture by the nucleus is theoretically possible but the motion of the nucleus leads to an energy mismatch which effectively prevents absorption.

10.0 RADIOACTIVE DECAY

When a nucleus emits a Beta-particle or a Gamma-ray then it is said to undergo RADIOACTIVE DECAY. Thus the amount of radioactive material in a source decreases with time. Radioactive decay is a random process and it is not possible to predict exactly when any one particular atom will decay. Only the PROBABILITY of disintegration in a particular period of time can be stated. This probability always remains the same. It has been found that the amount of activity is proportional to the number of active nuclei present in the source and the decay follows an exponential law.

The probability of disintegration per unit time interval is called the DECAY CONSTANT and is denoted by the Greek letter LAMBDA (λ). It is possible to show that, if N is the number of active atoms in a source at a time 't' after the source has been made and N_o was the original number then:

$$N = N_o e^{-\lambda t}$$

The decay constant is rather an awkward quantity to handle and it is more convenient, and useful, to use the concept of HALFLIFE ($t_{1/2}$). This is simply defined as the time in which the number of active atoms falls to half its initial value. If we substitute $t = t_{1/2}$ in the above equation we can show that:

$$\lambda = \frac{0.693}{t_{1/2}}$$

where 0.693 is the value of the logarithm of 2 to the base e - the base of natural logarithms. We can then write the decay equation as:

$$N = N_o e^{-0.693t/t_{1/2}}$$

It is important to remember that when using the decay equation the units of time for t AND for $t_{1/2}$ must be in the same time units.

11.0 UNITS OF ACTIVITY

Activity is measured in disintegrations (or nuclear transformations) per unit time (usually seconds or minutes) and this is related to the count rate (counts per second) measured by a radiation detector. It should be remembered that activity and count rate (under constant conditions of detection) decay with the same law as for nuclei. The unit of activity that is in current use is the BECQUEREL (Bq) which is defined as that amount of material which undergoes one nuclear transformation per second.

The former unit of activity was the CURIE (Ci). This was defined as that quantity of a nuclide that had a disintegration rate of 3.7×10^{10} per second. This is equal to the disintegration rate of one gramme of ^{226}Ra. Thus:

$$1 \text{ Bq} = 1 \text{ dps}$$

and

$$\begin{aligned} 1 \text{ Ci} &= 3.7 \times 10^{10} \text{ Bq} \\ &= 37 \text{ GBq} \end{aligned}$$

12.0 RADIATION DOSE

When radiation interacts with matter a certain quantity of energy is released.

The original international unit of radiation is called the RÖENTGEN (R) after Wilhelm Röentgen - the discoverer of X-rays. The Röentgen is defined as the radiation dose which releases 2.58 Coulombs of electrical charge per kgm of dry air. 1 Rad (Radiation Absorbed Dose) is the dose that will deposit 100 ergs of energy in a gram of material. In air 1R = 1 Rad. The new metric unit is the GRAY (Gy) and this is the dose that will deposit 1 JOULE of energy in 1 kg of material. Thus 1 Gray = 100 rads.

The Rem (Röentgen Equivalent Man) is a biological rather than a physical unit of radiation. It is that dose of radiation that is equivalent in biological damage of a specified type to 1 R of photons (actually 1 R of 250 keV X-rays, consisting of photons with a variety of energies ranging from 50 eV to 250 keV). The new metric unit is a SIEVERT (Sv) and 1 Sv = 100 Rem.

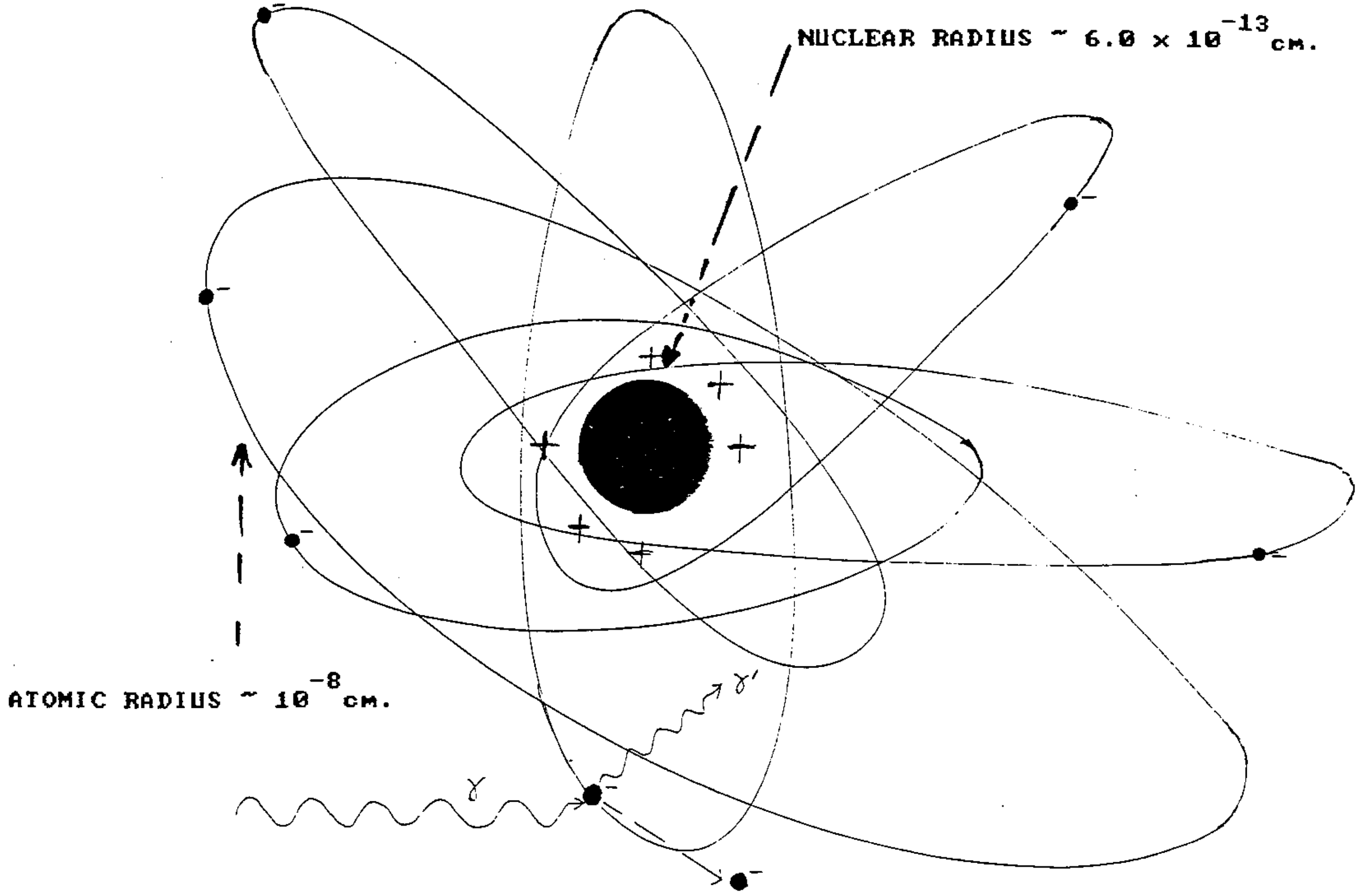

FIGURE 1

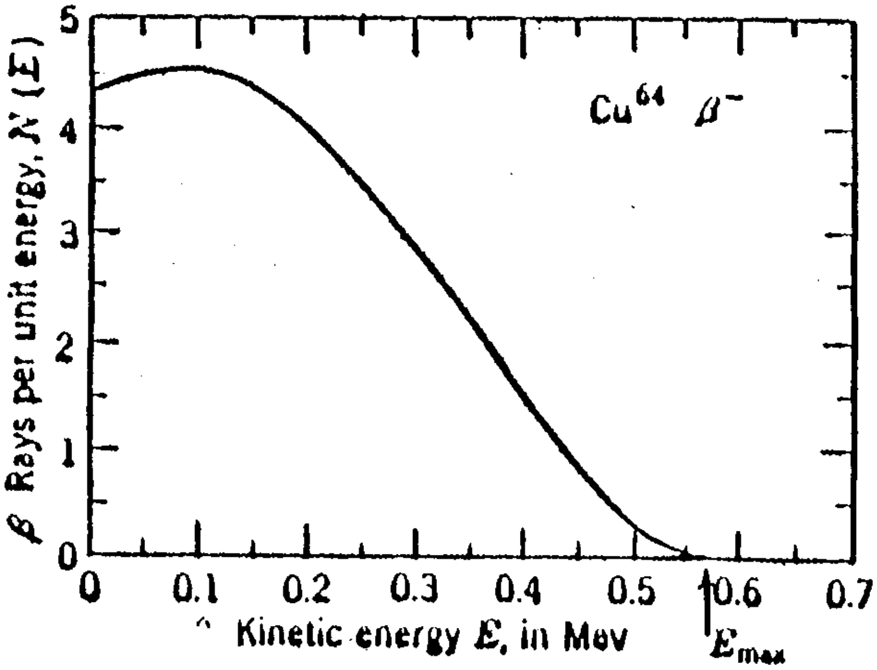

FIGURE 2 - Energy Distribution of β^- Particles from ^{64}Cu

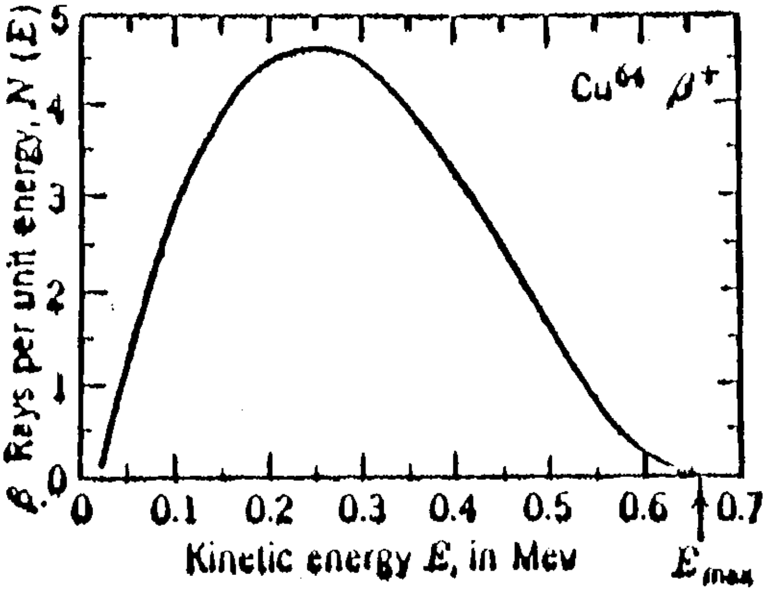

FIGURE 3 -- Energy Spectrum of β^+ Particles from ^{64}Cu

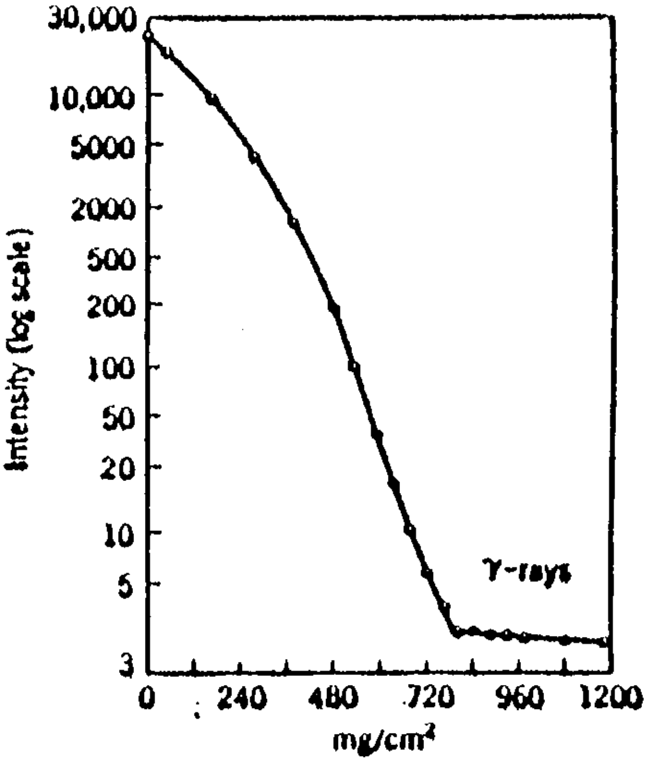

FIGURE 4 - Range-Energy Curve for Beta-particles

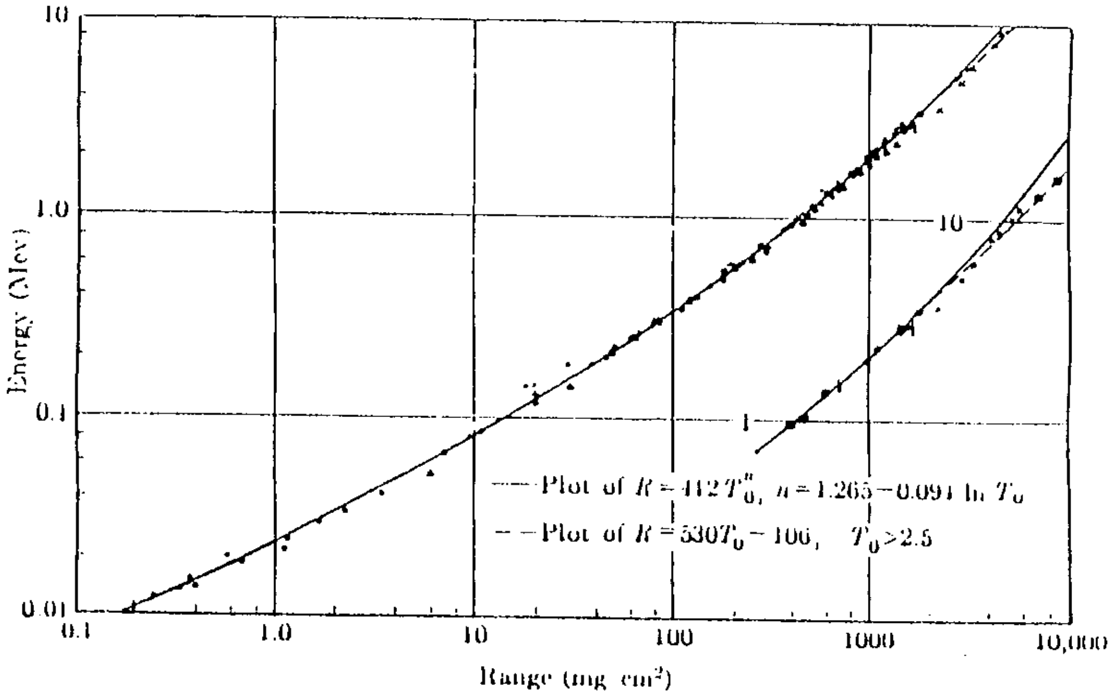

FIGURE 5 - A Semilogarithmic Absorption Plot for Beta Rays from P^{33}. The Derector was an Ionisation Chamber.

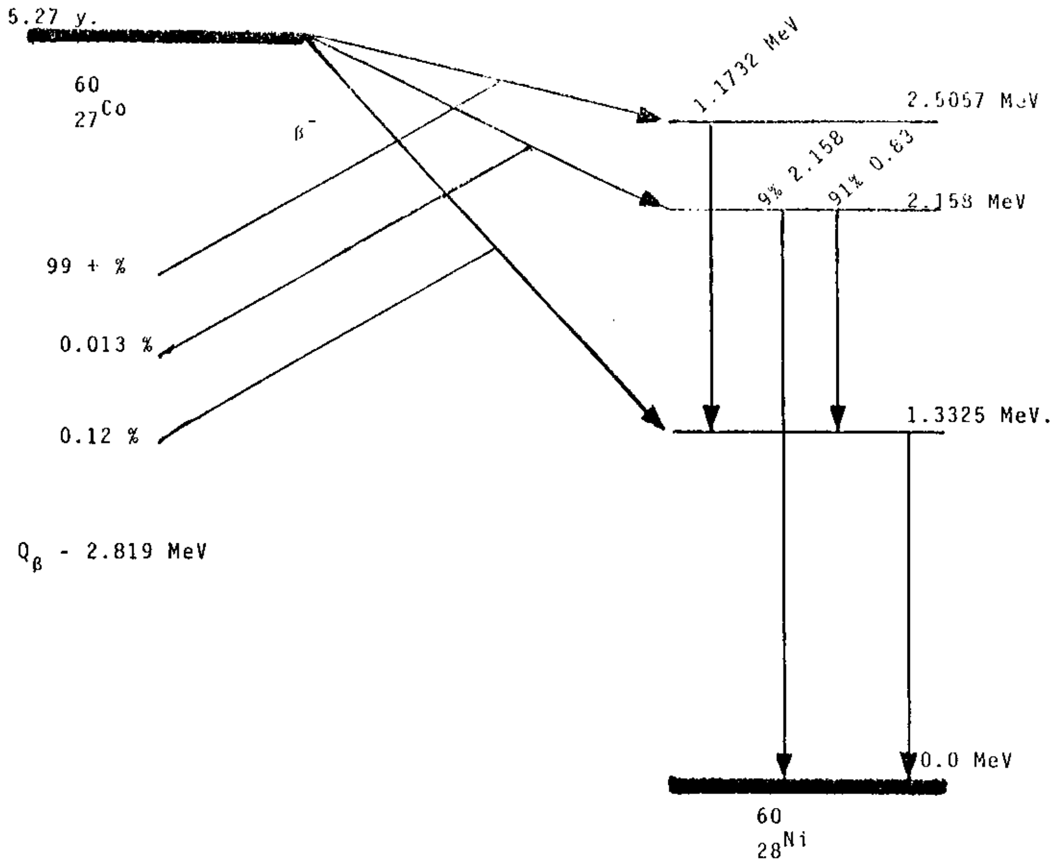

FIGURE 6 - Decay Scheme for ^{60}Co

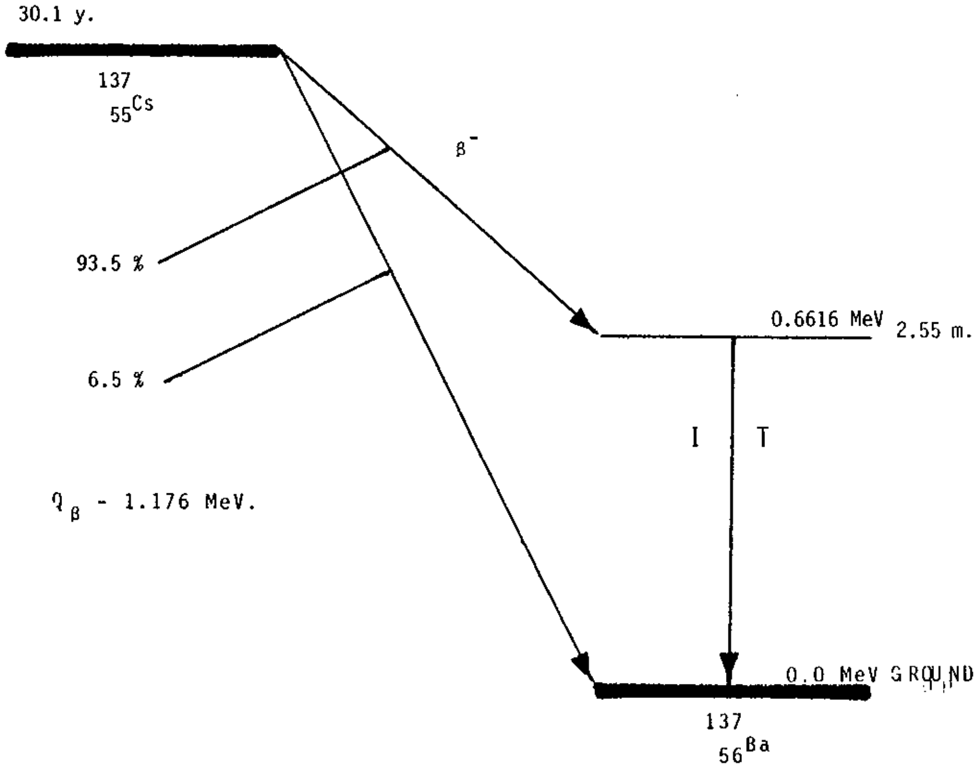

FIGURE 7 - Decay Scheme for ^{137}Cs

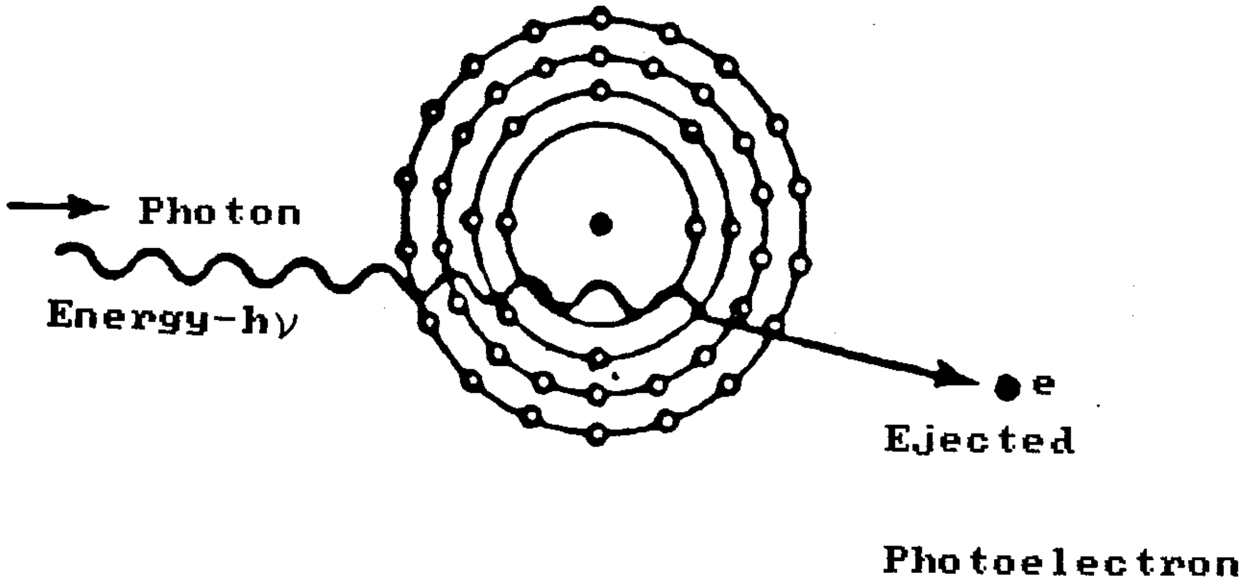

FIGURE 8 - The Photo-electric Effect

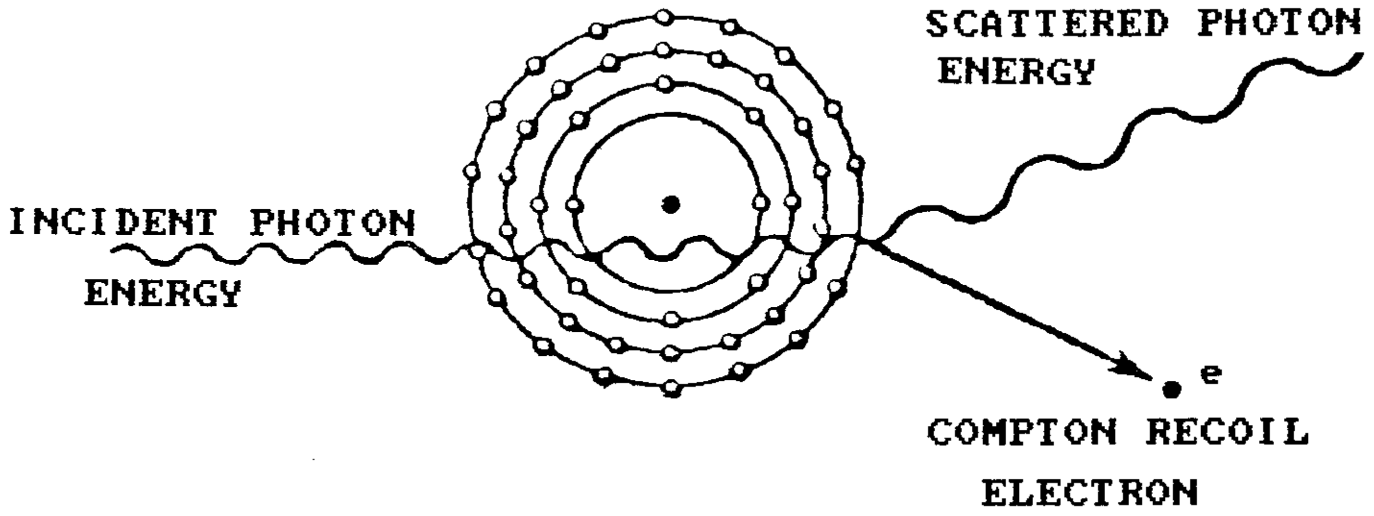

FIGURE 9 - The Compton Effect

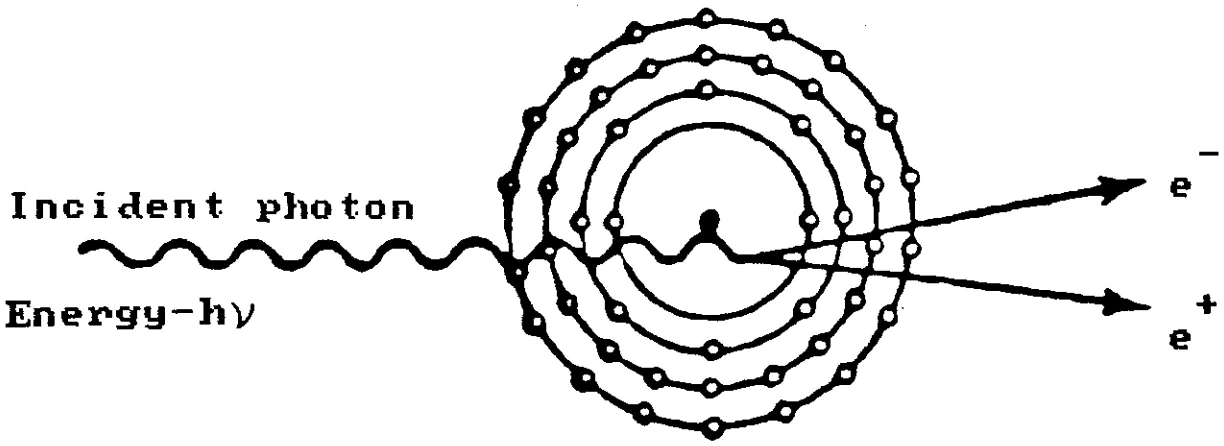

FIGURE 10 - Pair Production

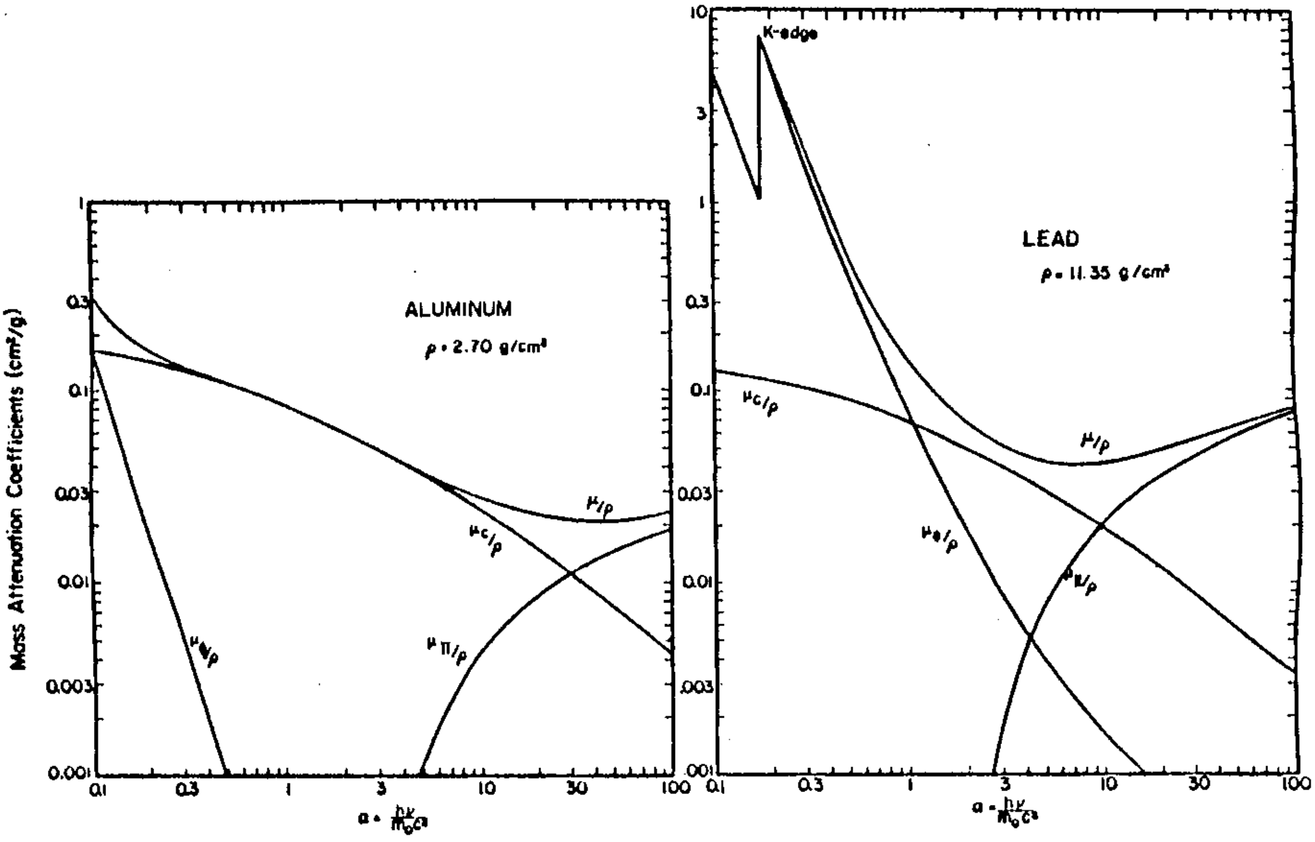

FIGURE 11 - The Mass Absorption Coefficients for Aluminium and Lead as a function of Gamma Energy in Units of $m_o c^2$ (i.e. Units of 0.511 MeV).

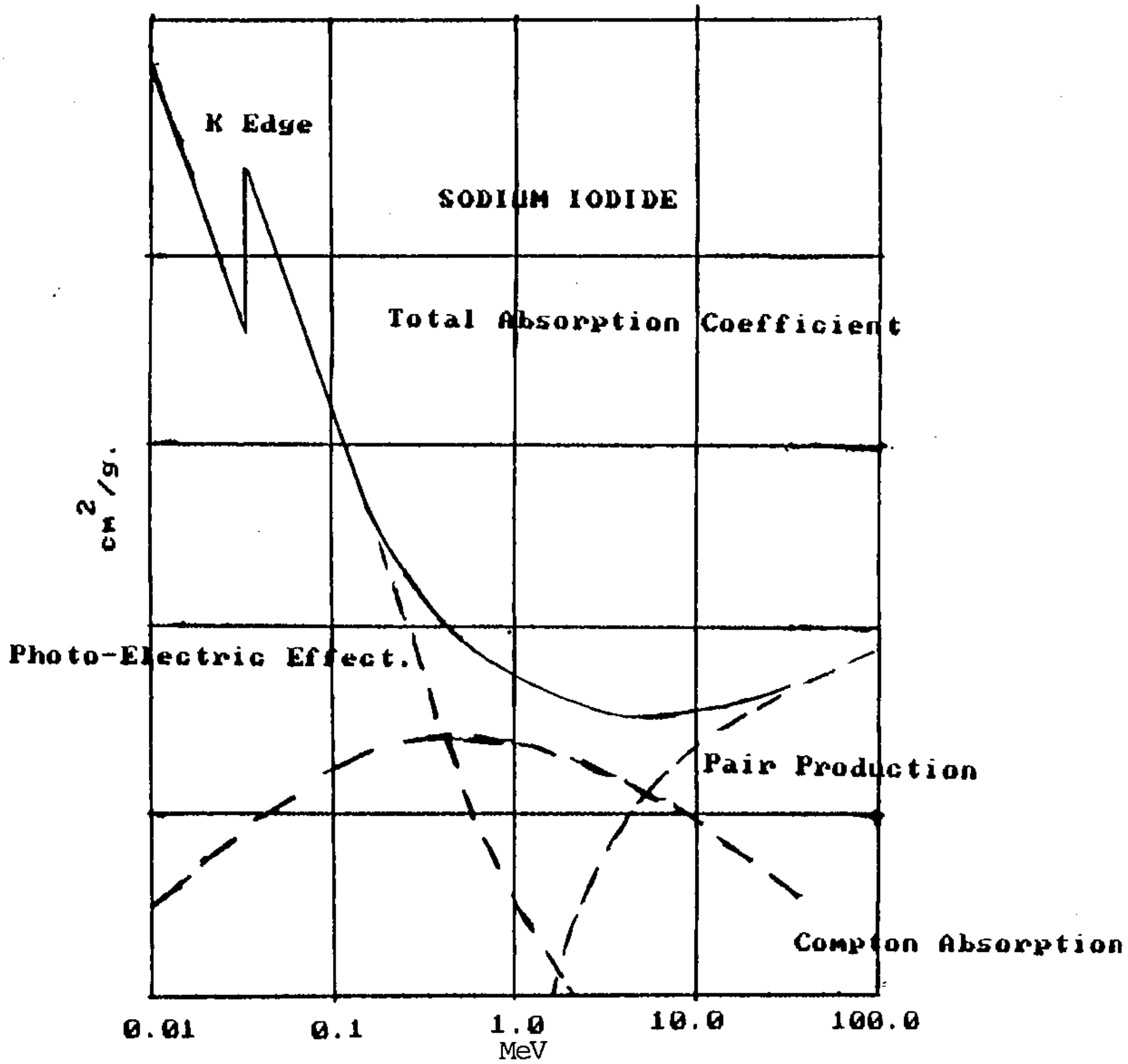

FIGURE 12 - Variation of Absorption Coefficients for NaI(Tl) with Energy

LECTURE 2

REMOVAL OF OFF-FLAVOURS IN SOME AUSTRALIAN CRUSTACEA BY IONISING RADIATION

D. FREEMAN

REMOVAL OF OFF-FLAVOURS IN SOME AUSTRALIAN CRUSTACEA BY IONISING RADIATION

DIANA J. FREEMAN

Australia is a major producer of crustacean foods, both for local consumption and export. However, the development of an export industry based on the deep sea royal red prawn, *haliporoides sibogae* and the shallow water shovel nosed lobster or balmain bug, *lbacus peronii* has been hampered by the sweet garlic off-flavour often encountered in both these species.

Analysis of headspace volatiles from homogenates of these creatures by combined gas chromatography-mass spectroscopy, g.c.-m.s. accompanied by sniffing of the effluent from a g.c. column showed that the garlic off-flavour composition was complex.

The royal red prawn contained two chemically distinct molecules responsible for the garlic off-flavour. One was the extremely volatile arsenic containing trimethylarsine $(CH_3)_3As$ and the other the sulphur based bis-(methylthio)-methane, $CH_3SCH_2SCH_3$. These compounds were routinely found in concentrations of 0.04 $\mu g\ kg^{-1}$ and 3.0 $\mu g\ kg^{-1}$ respective

The balmain bug also contained both bis-(methylthio)-methane and trimethylarsine, however, these were found in vastly different concentrations compared to the royal red prawn. Trimethylarsine was estimated to be present at only 0.002 $\mu g\ kg^{-1}$, whereas bis-(methylthio)-methane was present at much higher concentrations ranging from 20 to 100 $\mu g\ kg^{-1}$, and so is the predominant cause of the garlic off-flavour in the balmain bug.

Live balmain bugs showed no sign of the garlic off-flavour, however after death, some adult males developed this, and the concentration increased exponentially with time at ambient temperatures. Bis-(methylthio)-methane would appear to be an indicator of spoilage in some adult male balmain bugs.

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However, in the case of the royal red prawn the garlic flavour apparent immediately on landing the catch, was found in both sexes, and its concentration did not increase with time at ambient temperatures.

This species of prawn is trawled for in depths of 250-300 fathoms where water temperatures lie between 5 and 10°C. As this species is thin shelled and fragile, breakage of the shell and some damage to the flesh is incurred during trawling, which usually takes place over 2 hrs, and by the time the catch is landed, 99% of it is dead. Biochemical reactions leading to formation of off-flavours may therefore occur long before the catch is landed, and so it is difficult to assess if this is a spoilage problem.

So far it has been difficult to build up an export market for both of these species. The royal red prawn is present in vast quantities off the continental shelf, and as yet is not efficiently fished for. An attempt to build up an export market with France was in part unsuccessful because of the offensive garlic off-flavour. The Japanese were interested in importing balmain bug tails, however, the presence of the garlic off-flavour prevented the establishment of an export industry.

Recently a method for removing this noxious odour was developed which involved γ-irradiation of the affected crustacea using a cobalt-60 source. Irradiation as a method of food processing and/or extending shelf life of a variety of foods has been known for many years, and is now gaining acceptance as a viable adjunct to more traditional food treatments. However, this is the first documented case of γ-irradiation improving the flavour of the final product.

Eight freshly caught male balmain bugs were snap frozen in liquid nitrogen, and then cut in half longitudinally. At this stage it was observed that four of the curstacea had an offensive garlic-like odour. While still frozen, each crustacean was subjected to γ-irradiation, one half of each was given a dose of 25 kGy and the other a dose of 5 kGy.

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At the end of the treatment, the halves treated with the higher dose showed no sign of the off-odour, while those at the lower dose still had a slight odour which did not increase in intensity after storage at room temperature for 24 hrs. Under normal circumstances the garlic like odour would have increased rapidly with time on thawing. From these experiments it would appear that a high dose of γ-irradiation completely removes the existing off-odour, and also prevents its further formation. At the lower doses the off-odour is not completely removed and again no further increase in its concentration is apparent.

An aqueous solution of bis-(methylthio)-methane, the compound mainly responsible for the garlic like odour in balmain bugs was irradiated with a dose of 25 kGy. Examination of this solution after treatment showed that it was odourless and that bis-(methylthio)-methane had been destroyed.

A further trial irradiation was carried out on royal red prawns contaminated with the garlic like off-flavour. Samples were irradiated at much lower doses than the balmain bugs, the doses given were 0.5 and 1.0 kGy. Irradiation removed all traces of the off-flavour, but in those irradiated at the higher dose a slight burnt flavour was noticeable.

Examination of the irradiated aqueous solution of bis-(methylthio)-methane showed that sulphonic acid was present. Presumably the other expected product would be methanol. However, it is extremely difficult to detect small quantities of methanol in an aqueous environment.

It is of interest to note that in both the irradiated crustacea and the irradiated aqueous solution of bis-(methylthio)-methane no methane thiol, CH_3SH or hydrogen sulphide, H_2S were detected. These could be expected radiolysis products of bis-(methylthio)-methane if the environment was sufficiently reducing.

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The other component responsible for the garlic off-flavour, especially in the royal red prawn is trimethylarsine. No irradiation work on this compound has been carried out to date for two reasons. Firstly, trimethylarsine is extremely toxic, in fact trialkylated arsines represent the most toxic form of arsenic because of their pronounced lipid solubility. Secondly, not only is it extremely volatile, but it oxidises very rapidly and so presents handling problems. Both of these factors make it impossible to conduct taste panel work on trimethylarsine.

Further work is to be carried out to establish the correct doses required for the removal of the off-flavour without production of further undersirable flavours in both species of crustacea examined.

This work was carried out at the CSIRO Division of Food Research under the supervision of Dr. F.B. Whitfield.

The help of Mr. M.E. Izard of the Isotope Division, AAEC is gratefully acknowledged.

DIANA J. FREEMAN
(1985)

LECTURE 3

SOME ASPECTS OF RADIOLOGICAL PROTECTION

J. BUTTON

SOME ASPECTS OF RADIOLOGICAL PROTECTION

J.C.E. BUTTON
CHIEF, HEALTH AND SAFETY DIVISION
AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS RESEARCH LABORATORIES

SOME ASPECTS OF RADIOLOGICAL PROTECTION

1. INTRODUCTION

It is an unfortunate fact that the average person has little understanding of ionising radiations or radioactive materials. They have become emotive issues and are often treated with suspicion. When they are featured in an item in the news media needless anxiety may be caused and the uninformed may be forgiven for concluding that:

- they are new phenomena which have only recently been discovered,
- little is known about them, and
- they are always extremely hazardous, even when closely controlled or present in small amounts.

In fact:

- ionising radiations have been closely studied, and well understood, for eighty years,
- radioactivity is a natural phenomenon which was first discovered towards the end of the last century,
- much more is known about ionising radiations, and radioactive materials than is known, for example, about many of the wide variety of chemical compounds in use throughout the world.

Mankind has always lived in an environment containing ionising radiations and radioactive materials and during the past eighty years or so we have learned a great deal about them. Small amounts of radioactive materials are present naturally in air, water, food, soil, building materials and our bodies. We are constantly exposed to a low level of ionising radiation from these sources and from cosmic rays; this is known as the natural background radiation (1).

Radioactivity, a natural phenomenon, was first discovered towards the end of the nineteenth century and subsequent investigation soon gave an understanding of the nature of properties of ionising radiation and radioactive materials.

Atoms of the various chemical elements and molecules of their compounds are present in various combinations in all matter. Most atoms are stable but some are unstable and undergo spontaneous changes which ultimately transform them into stable atoms. These unstable atoms are radioactive and the resultant transformation is the radioactive disintegration or decay process which is usually accompanied by an emission of charged particles or gamma rays. The decay rate of a given radioactive species is characterised by its half life which is the time taken for half of the radioactive atoms in a given sample to disintegrate. Radioactive half lives range from fractions of a second to millions of years.

Soon after their discovery it was realised that radioactive materials and ionising radiations are potentially harmful if misused and recommendations for their safe use were formulated earlier this century. The International Commission on Radiological Protection (ICRP) an independent non-governmental expert body was established in 1928 to formulate radiation protection recommendations to be used for protection of individuals. Its members are chosen on the basis of their individual merit in the fields of medical radiology, biology, genetics, radiation protection physics, health physics, biochemistry and biophysics. The Recommendations of the ICRP (2) have been universally accepted for the last 50 years or so and are incorporated into national and international codes of practice and legislation.

Following the discovery of naturally occurring radioactive materials (e.g. uranium, thorium, radium), research workers developed artificially produced radioisotopes. The development of the nuclear reactor in the early 1940s made available a much wider range of man-made radioisotopes in increasing amounts. These find ever-increasing applications in many fields of human endeavour.

2. IONISATION

If one or more of the orbital electrons of an atom are forcibly removed from their orbits, whilst the nucleus is unaffected, the resultant atom is no longer electrically neutral but has a net positive electric charge the size of which depends on the number of electrons lost. The resultant charged atom is called an ion, and in this particular instance it is a positive ion. The orbital electrons which have been removed may remain free for a period of time, but will usually attach themselves to other atoms forming atoms with extra orbital electrons. In this case the resultant atoms are negative ions. Ionisation is thus defined as the result of a process whereby an electrically neutral atom acquires either a positive or negative net charge. The radiations given off when radioactive atoms disintegrate are capable of interacting with the atoms of materials through which they pass and in doing so they produce ionisation in the material. Radiations, such as x-rays, from radiation-producing machines are also capable of causing ionisation.

Ionisation may be produced either by directly ionising particles or by indirectly ionising particles. Directly ionising particles are defined as charged particles (e.g. electrons, protons, alpha particles) which have sufficient kinetic energy to produce ionisations by collision. Indirectly ionising particles are uncharged particles (e.g. neutrons, photons) which can liberate directly ionising particles or can initiate nuclear transformations. Ionising radiation is any radiation consisting of directly or indirectly ionising particles or a mixture of both.

3. NATURAL BACKGROUND IONISING RADIATION (1)

Radioactivity is a natural phenomenon which was first discovered towards the end of the nineteenth century but before then, throughout the whole of his history, man had been subjected to small amounts of natural background radiation from his surroundings. Small amounts of radioactive materials are present in air, food and water, all of which give rise to a source of background internal radiation.

The amount of external natural background radiation will vary from one place to another over the earth's surface depending, amongst other things, on the amount of natural radioactive materials present in local rocks and soil, the altitude of the locality etc.. These natural sources of radiation are always present and are inescapable and man has adapted himself to this background radiation and so far as is known this level of radiation causes no harm. Typical annual gonad dose due to natural background radiation is shown in Table 1.

In a small number of areas the dose rate from natural background is considerably higher than that experienced by populations in the major proportion of the world. This high radiation background is due to the presence of larger than normal amounts of naturally occurring radioactive materials in the soil, drinking water, air, building materials etc. and also to the cosmic ray altitude effect (i.e. the contribution from cosmic rays increases with altitude).

There are five known inhabited areas where there is increased radiation from rock or soil. These are in Brazil, France, India, Niue Island and the United Arab Republic. In Brazil the maximum external background dose rate has been estimated at about 120 millisieverts per year.

4. IONISING RADIATIONS FROM RADIOACTIVE ATOMS

The three main types of radiation which may be given off by the disintegration of radioactive atoms are alpha particles, beta particles and gamma rays. The energies of these ionising radiations are usually expressed in units of millions of electron volts (MeV).

Alpha (α) particles are identical with helium nuclei, having two protons, each carrying a unit positive charge, and two neutrons. Alpha particles are usually emitted by heavy radioactive atoms, such as uranium and radium. Their initial speed of emission from the nucleus of a disintegrating radioactive atom may be of the order of 1.5×10^9 centimetres per second, but they quickly dissipate their energy by colliding with the atoms of the material through which they travel causing ionisation to take place. Thus alpha particles have very little power of penetration and a thin sheet of paper, the outer layer of human skin or a few centimetres of air will stop them completely.

Beta (β) particles are high speed electrons from the nuclei of radioactive atoms. The maximum speed of emission of a beta particle may be very nearly equal to the velocity of light (3×10^{10} centimetres per second). A beta particle has a greater penetrating ability than an alpha particle of the same energy, but will be stopped by a few millimetres of aluminium, a centimetre or so of human tissue or a few metres of air.

Gamma (γ) rays are electro-magnetic radiations similar to x-rays, and travel at the speed of light. They have a high penetrating power and can travel through several hundreds of metres of air or many centimetres of dense materials such as iron or lead.

The other type of radiation which may be encountered, for example, around nuclear reactors, consists of neutrons. These are uncharged particles with energies which may range from a fraction of an electron volt up to several MeV. Because neutrons are uncharged there is no nuclear potential barrier affecting their travel through shielding material and no interactions with the planetary electrons. Neutrons may thus have a high penetrating ability and methods adopted for shielding depend on the neutron energy.

It must be emphasized that ionising radiations produced by radioisotopes (α, β and γ radiations) and by x-ray machines do not induce radioactivity in any person or object irradiated by the radiation. The radiation will cause ionisation, but will not leave any residual radioactivity.

5. THE HAZARDS OF IONISING RADIATIONS

None of the human senses will give warning of the presence of ionising radiations; they can be detected and measured only by special devices which include geiger tubes, ionisation chambers, scintillation counters, film badges and thermoluminescent dosemeters.

When ionising radiation strikes the human body it will penetrate to a depth which depends on the type and energy of the radiation. Inside the body, part or all of the incident radiation will be absorbed. The living cells of which the body is composed will be affected when energy arising from the resulting ionisation caused by the radiation, is absorbed in the complex structure of the cells. Molecular ions will be produced which can interfere with the natural chemical reactions in the cells and may give rise to harmful biological effects. Within certain limits the damage thus caused may be repaired by the body so that there is no apparent effect, but if excessive amounts of radiation are received then some harm may result.

6. RADIATION PROTECTION STANDARDS (2,3)

Radiation protection is concerned with the protection of individuals, their progeny and mankind as a whole, while allowing necessary activities from which exposure to ionising radiation might result. The detrimental effects from ionising radiation against which protection is required are:

- somatic effects which are manifested in the exposed individual,
- genetic effects which are manifested by effects on the descendants of the exposed individual.

Somatic effects are those effects which give rise to injuries to the cells concerned with maintenance of body functions of the individual who received the ionising radiation e.g. cells in the blood and bone marrow. Genetic effects are those effects which may give rise to injuries in the sex cells which transmit hereditary characteristics to the unborn children of the individual who receives the ionising radiation.

"Stochastic" effects are those for which the probability of an effect occurring, rather than its severity, is regarded as a function of dose, without threshold. "Non-stochastic" effects are those for which the severity of the effect varies with the dose, and for which a threshold may therefore occur. At the dose range involved in radiation protection, hereditary effects are regarded as being stochastic. Some somatic effects are stochastic; of these, carcinogenesis is considered to be the chief somatic risk of irradiation at low doses and therefore the main problem in radiation protection.

Some non-stochastic somatic effects are specific to particular tissues, as in the case of cataract of the lens, non-malignant damage to the skin, cell depletion in the bone-marrow causing haematological deficiencies, and gonadal cell damage leading to impairment of fertility.

The aim of radiation protection should be to prevent detrimental non-stochastic effects and to limit the probability of stochastic effects to levels deemed to be acceptable. An additional aim is to ensure that practices involving radiation exposure are justified.

The recommendations of the International Commission on Radiological Protection (ICRP) contain information on permissible exposure to ionising radiations and to radioactive materials. The former are expressed as dose-equivalent limits (DEL) and the latter as annual limits of intake (ALI).

The ICRP recommendations deal with radiation protection standards for two classes of persons:

- radiation workers (i.e. adults exposed in the course of their work),
- members of the public.

The ICRP points out that it is not desirable to expose members of the public to risks as great as those considered acceptable for radiation workers and recommends that dose-equivalent limits for members of the public should be lower than those for radiation workers by a factor of ten.

6.1 Dose-equivalent limits for radiation workers

The dose-equivalent limits recommended by the ICRP are not maximum limits in the sense that an individual will inevitably incur significant injury if a particular value is exceeded. However, as any exposure may involve some degree of risk, any unnecessary exposure should be avoided and all doses kept as low as can reasonably be achieved. The dose-equivalent limits recommended provide a basis for planning working procedures, for designing the in-built protection that is desirable, for assessing the efficiency of protective measures and practices and for determining the extent and nature of the health surveillance which should be applied for particular individuals. Experience over recent years has shown that it is rare for the dose-equivalent limits recommended by the ICRP to be approached by radiation workers.

In assessing the radiation dose to any organ or tissue account must be taken of the dose contributed by external and internal sources resulting from the circumstances imposed by the occupation and by those components of background radiation that result from man-made activities or special environments, (i.e. enhanced background radiation as distinct from normal natural background radiation). The doses from any exposure received as a patient, from exposures to normal natural background radiation or from other exposures received by the individual as a member of the public are not to be taken into account. Whether any component of enhanced natural background radiation should be subject to the system of dose limitation must be a matter of judgement having regard to the circumstances.

6.2 Dose-equivalent limits for individual members of the public

Dose limitation for members of the public is a more theoretical concept than dose limitation for radiation workers. Whereas it is practicable to monitor the radiation doses received by radiation workers the dose-equivalent limits recommended for members of the public are intended to provide standards for the design and operation of radiation sources so that it is not likely that individual members of the public will receive more than a specified dose. The effectiveness of the design and operating procedures, with respect to members of the public, are not normally checked by the monitoring of the individual doses but are assessed through sampling procedures in the environment, through area monitoring and through control of the sources from which the exposure may arise.

6.3 Annual dose-equivalent limit

The annual dose-equivalent limits for the whole body are defined for stochastic effects only and are:

. radiation worker	50 millisieverts
. member of public	5 millisieverts

Derived annual dose-equivalent limits for body organs or tissues when irradiated singly are given in reference 3.

These annual dose-equivalent limits are not "target" figures in the sense that a person's exposure should be just within these prescribed limits. Since exposure to ionising radiation may involve some degree of risk the ICRP (2) and the Australian National Health and Medical Research Council (3) recommend that all exposures should be kept as low as reasonably achievable, economic and social factors being taken into account.

Harm may be caused if persons are exposed to excessive amounts of ionising radiation or if significant amounts of radioactive material are taken into the body. Depending on the circumstances such high exposures could lead to adverse effects in individuals such as radiation burns, radiation sickness or subsequently cancer. Gross overexposure of this type is readily avoidable if commonsence safety measures are used. Ionising radiations and radioactive materials can be used safely, provided that proper precautions and controls are invoked.

Each State in Australia has legislation (4) relating to protection against exposure to ionising radiations; permissible levels of exposure to ionising radiations and radioactive materials in this legislation are based on the recommendations of the ICRP (2) and the Australian National Health and Medical Research Council (3).

7. RADIATION AND RADIOACTIVE CONTAMINATION

It is important to understand and distinguish between, the terms "radiation" and "radioactive contamination".

Radiation refers to the actual ionising radiation given off by a radioactive source or a device which produces ionising radiation (e.g. an x-ray machine). A person who is exposed to external x-radiation from an x-ray machine, or gamma radiation from a gamma-emitting radioactive source, is irradiated but does not, in consequence become contaminated or radioactive.

Radioactive contamination may be defined as radioactive material which is unconfined or is in an undesired location. Examples are radioactive material (e.g. powder or liquid) spilled on a bench top, the floor or a person's hand or radioactive material dispersed into the air (airborne contamination). Radioactive contamination always has some ionising radiation associated with it; an external radiation hazard may arise if the contamination is present in sufficient quantity and if it emits penetrating radiation.

8. SAFETY MEASURES WITH IONISING RADIATIONS AND RADIOACTIVE MATERIALS

The safety measures employed with ionising radiations and radioactive materials are used and designed to minimise the possibility of harmful effects to persons. This is achieved by ensuring that:

> exposure to ionising radiations is kept below the maximum permissible levels,

- radioactive materials are prevented from entering the body.

Exposure to ionising radiation may be of two forms:

- external radiation exposure - when the source of radiation is external to the body, e.g. when a person is exposed to radiation from an x-ray machine or to the radiation from an encapsulated gamma emitting source, and
- internal radiation exposure - when unsealed radioactive materials (e.g. powders, gases) are taken into the body by a mechanism such as inhalation, ingestion or absorption through a wound or the intact skin.

8.1 Protection against external radiation hazards

When an external radiation hazard is involved, three factors which may be invoked, either singly or together, to protect persons are:

- time - i.e. minimise the time spent in a field of ionising radiation;
- distance - i.e. maximise the distance between a person and a source of ionising radiation. (For a "point" source which emits gamma radiation the intensity of radiation decreases inversely as the distance from the source; this is the so-called inverse square law); and
- shielding - i.e. interpose adequate amounts of appropriate shielding material between a source of ionising radiations and persons in its vicinity. (Alpha radiation does not constitute an external radiation hazard. For beta radiation, only small thicknesses of low density shielding material e.g. aluminium or plastics are required; X and gamma radiation require larger thicknesses of denser materials such as lead or steel; neutrons require larger thicknesses of materials such as concrete, pariffin wax or other materials containing a high percentage of hydrogen atoms).

8.2 Protection against internal radiation hazards

- ensuring unsealed radioactive materials are properly contained,
- using appropriate instruments to ensure that no radioactive material has escaped from its containment,
- promptly cleaning up any radioactive spillages which may occur, while appropriately protecting the persons engaged in the cleanup.

9. RADIOLOGICAL MONITORING EQUIPMENT AND METHODS

The efficient control of radiological hazards may be achieved by evaluation and measurement of potential hazards, by proper interpretation of the results of the measurements and by provision of appropriate safeguards. Since nuclear radiations are not recorded by the human senses, appropriate instruments and other devices are necessary to detect the ionising events which these radiations produce.

During the past several decades a wide variety of monitoring equipment has been developed for use in radiological protection programs; some of the developments finding general widespread use whilst others have been restricted to highly specialised applications. Two major themes of these protection programs may be defined as provision of protection against the two types of radiological hazard - external and internal. To this end the monitoring services required may be divided into the two broad categories of radiation monitoring and contamination monitoring.

Each of these monitoring categories needs a number of instruments or other detecting devices to perform a variety of functions such as:

- radiation monitoring
    - installed area radiation monitors (indicating and alarm types)
    - portable radiation monitors (survey instruments),
    - devices for monitoring external radiation dose received by personnel.
- contamination monitoring:
    - monitors for checking contamination of air in the breathing zone,
    - monitors for checking contamination of surfaces,
    - monitors for checking internal contamination of personnel.

9.1 Devices for Monitoring External Radiation Doses Received by Personnel

A commonly used device for measuring the external radiation dose to personnel is the photographic dosemeter or film badge. A piece of x-ray film in a light-tight envelope is enclosed in a holder which contains a number of radiation filters which are used to:

- make the film response energy independent,
- permit assessment of doses of different types of radiation.

The normal type of film badge enables measurement to be made of doses due to:

- beta radiation,
- x-rays,
- gamma rays,
- slow neutrons.

The ionising action of radiations on the film emission gives rise to a latent image on the film which causes it to "blacken" after development, the degree of blackening being a measure of the dose received. The film pack may often contain two emulsions of differing sensitivities; the high sensitivity emulsion being for monitoring of normal radiation doses and the low sensitivity emulsion being for monitoring of high doses (disaster monitoring).

To measure fast neutron exposure a special film pack consisting of a thin polythene sheet sandwiched between two nuclear emulsions is used. The assembly is wrapped in a light tight envelope and partly covered with a cadmium filter to absorb slow neutrons. The tracks produced by proton recoils from neutron interactions in the emulsion are counted to give a measure of the dose to fast neutrons.

All photographic dosemeters must be calibrated and sets of "standard" films are exposed to known doses of radiation and are used to produce calibration graphs. The gamma dose range which may be measured by normal film badges is usually from 200 microsieverts to about 10 millisieverts.

Film dosemeters are usually worn on the chest to give an indication of whole body penetrating radiation dose. As the need arises films may also be worn on the head, wrist, ankles, or any other part of the body. For use on the fingers special finger ring holders may be used.

Film badges may often be supplemented by other direct or indirect reading dosemeters.

A commonly encountered direct reading dosemeter for this purpose is the quartz fibre electroscope (QFE) which is slightly larger than a fountain pen. It consists of a quartz fibre electroscope in a small ionisation chamber and an optical system to observe the image of the quartz fibre on a scale which gives a reading of the dose recorded. This type of dosemeter is normally available in several ranges and is used to measure gamma radiation in the energy range from about 50 keV to 2 MeV. Instruments of this type are also obtainable for measurement of doses due to beta radiation or slow neutrons.

Other devices available for measurement of external doses to personnel include solid state devices using the phosphate glass radiophotoluminescent (RPLD) dosemeter and the thermoluminescent dosemeter (TLD) both of which are indirect reading types.

The phosphate glass dosemeter responds to gamma radiation and is based on the principle that certain glasses containing metaphosphate salts fluoresce under ultra-violet light after gamma irradiation. The fluorescence is usually in the yellow light region and its intensity is a measure of the radiation exposure.

The thermoluminescent dosemeter consists of a material which has the property such that when it is heated after being subject to irradiation it emits a quantity of light which is proportional to the amount of radiation absorbed. This type of dosemeter consists of a suitable quantity of thermoluminescent material; suitable materials which have been used include lithium fluoride and calcium fluoride and these dosemeters may be used to measure doses due to gamma, beta, and neutron radiations. Lithium fluoride dosemeters have been shown to be almost independent of photon energy over the range 30 keV to 2 MeV, and it is claimed that some thermoluminescent dosimetry systems have a measuring range from a few tens of microsieverts to several tens of sieverts. Thermoluminescent dosemeters have found application in determining finger tip doses when close handling radioactive materials.

Other personnel external radiation dosemeters may use miniature geiger tubes in small instruments (signalling dosemeters) which are usually carried in a pocket to give an audible warning when a predetermined dose rate is exceeded or will give a warning note which increases in frequency with dose rate. Recently miniature pocket instruments of similar type have been produced which give a digital readout of the dose received.

9.2 Methods of Monitoring Internal Contamination of Personnel

Bioassay procedures are available to monitor internal contamination of persons. Samples of urine or faeces may be analysed for radioactive content to give an estimate of the amount of contaminant radionuclide(s) in the body. In a few cases breath analyses may also be useful.

If the contaminant radionuclide in the body emits gamma radiation then the person may be placed in a special counter known as a whole body monitor and gamma spectrometrey techniques used to assess the amount and type of radionuclide(s) present in the body.

If radionuclide is accidentally taken into the body it will concentrate in the thyroid gland. A thyroid counter placed appropriately near the neck of the person can be used to estimate the amount of radioiodine in the thyroid.

In the event of accidental irradiation of a person with a high dose of neutrons ^{24}Na will be produced in the blood by neutron activation. An appropriately calibrated detector placed near to the back of the irradiated person may be used to give an estimate of the neutron dose received.

10. THE INTERNATIONAL SYMBOL DENOTING THE PRESENCE OF IONISING RADIATIONS (5)

Figure 1 shows the internationally agreed symbol used to denote the actual or potential presence of ionising radiation and to identify objects, devices, materials or combinations of materials which emit ionising radiation. It is known as the "trefoil" sumbol, and is coloured black, often on a yellow background. Such a symbol is found on transport packages containing radioactive materials and at the entrance to areas where ionising radiations and/or radioactive materials are in use. It is also displayed at the entrance to any area where radioactive materials are stored and where there are devices or machines which generate ionising radiation.

11. UNITS FOR THE MEASUREMENT OF RADIOACTIVITY AND OF IONISING RADIATION (6)

Within recent years international system (SI) units for the measurement of radioactivity and of ionising radiation have been introduced to replace the old non-SI units. Reference 6 gives relevant details.

The SI unit of dose-equivalent is the sievert (Sv) which replaces the non-SI unit, the rem. The sievert is equivalent to one joule per kilogram.

$$1 \text{ Sv} = 1 \text{ J/kg} = 100 \text{ rems}$$

12. RADIOLOGICAL ACCIDENTS

The potential for harm if ionising radiations and radioactive materials are used unsafely was realised prior to their widespread use. Strict safety standards were thus introduced leading to a good safety record over the past several decades during which extensive experience has been gained in the use of ionising radiations and radioactive materials (7). During this period there has been a significant expenditure in terms of money and manpower to minimise the possibility of occurrence of radiological accidents. In spite of this effort some accidents have occurred, many of which have been caused by human error. As in other fields of human endeavour the absolute prevention of accidents when using ionising radiations and radioactive materials may not be possible.

A radiological accident may be defined as an unforeseen occurrence involving exposure of humans and their environment to unexpected ionising radiation or radioactive contamination.

13. REGULATIONS FOR THE SAFE TRANSPORT OF RADIOACTIVE MATERIALS (8,9)

These regulations, from whatever source (e.g. IATA, IAEA etc), are designed to ensure safety when radioactive materials are transported, and to reduce the hazards, both to workers in the transport industry and to the general public, to acceptably low levels. Such safety is achieved by ensuring that packaging is designed so that:

- radioactive and fissile materials are adequately contained,
- ionising radiations emitted from the packages are at an acceptably low level,
- radioactive contamination on packages is non-existent, or within acceptable limits,
- heat generated by radioactive material within the package is dissipated adequately, and
- for fissile materials, there is no likelihood of criticality developing.

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TABLE 1

NATURAL BACKGROUND IONISING RADIATION

Source	Annual dose to gonads (microsieverts)
External irradiation	
Cosmic rays:	
. Ionising component	290
. Neutrons	7
Terrestrial radiation including air	500
Internal irradiation	
^{40}K	200
^{87}Rb	3
^{14}C	7
^{210}Po	3
^{222}Rn (dissolved in tissue)	3
Total	1000

Basic ionizing radiation symbol

SHAPE AND PROPORTIONS OF SYMBOL

The basic symbol for signifying ionizing radiation or radioactive materials shall be designed and proportioned as illustrated in the figure.

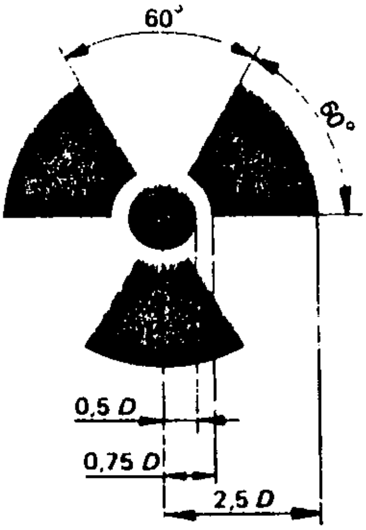

FIGURE 1

GLOSSARY

The following definitions are provided for the reader not familiar with some nuclear and other terms used in this paper.

ACTIVITY (of a substance)

The number of disintegrations per unit time taking place in a radioactive material.

ALPHA PARTICLE

A positively-charged particle from the nucleus of an atom emitted during radioactive decay. Consists of 2 protons and 2 neutrons (a helium 4 nucleus). Although alpha particles are normally highly energetic they travel only a few centimetres in air and, in fact, are stopped by a sheet of paper or the outer layer of dead skin. Hence, alpha particles are generally not an external radiation hazard to living matter; however, they may cause internal damage in the body, if taken in with the food and water we consume or the air we breathe.

ATOM

A particle of matter which cannot be broken up by chemical means. Atoms have a nucleus consisting of positively charged protons and uncharged neutrons of the same mass. The positive charges of the protons are balanced by a number of negatively-charged electrons in motion around the nucleus.

BACKGROUND RADIATION

The radiation in man's natural environment, including cosmic rays and radiation from the naturally radioactive elements.

BETA PARTICLE

A particle emitted from an atom during radioactive decay. Beta particles are essentially electrons with either negative or positive electric charge. Although beta particles are generally much less energetic than alpha particles they are much more penetrating because they have a much smaller mass than the alpha particle. High energy beta particles may travel many metres in air and are able to penetrate human skin: low energy betas are unable to penetrate the skin. Beta rays in general are easily shielded by a small thickness of light material, e.g. aluminium or plastic sheeting.

DECAY (e.g. radioactive decay)

The radioactive disintegration of an atomic nucleus resulting in the release of alpha, or beta particles or gamma radiation.

ELEMENT

A chemical substance that cannot be divided into simpler substances by chemical means; atomic species with the same number of protons.

GLOSSARY CONT'D

GAMMA RADIATION

Gamma radiation is electromagnetic radiation and is of the same physical nature as light, X-rays, radio waves, etc. However, gamma radiation is highly penetrating (more powerful than X-rays) and depending on its energy may require a considerable thickness of lead or concrete to absorb it completely, for example, tens of centimetres of lead or metres of concrete. Gamma radiation may cause ionisation in living matter and hence constitutes a biological hazard.

HALF LIFE (radioactive)

For a single radioactive decay process, the time required for the activity to decrease to half its value by that process.

IONISING RADIATION

Radiation (including alpha particles) capable of causing ionisation of the matter through which it passes and hence damage to living tissue.

IONISATION

Any process by which an atom, molecule, or ion gains or loses electrons.

ISOTOPE

Atoms of an element having the same number of protons but different numbers of neutrons in the nuclei, Isotopes usually have very nearly the same chemical properties, but somewhat different physical properties.

NEUTRON

An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen. Neutrons are the links in a chain reaction in a nuclear reactor.

NUCLEAR REACTOR

A structure in which a fission chain reaction can be maintained and controlled. It usually contains fuel, coolant, moderator, control absorbers and safety devices and is most often surrounded by a concrete biological shield to absorb neutron and gamma ray emission.

RADIOACTIVITY

The property of certain nuclides of spontaneously emitting particles or gamma radiation or of emitting X-radiation following orbital electron capture or of undergoing spontaneous fission.

RADIOISOTOPE

An isotope which is radioactive. Most natural isotopes lighter than lead-208 are not radioactive.

GLOSSARY CONT'D

SIEVERT

The sievert (Sv) is the SI unit for dose equivalent. The sievert is a large unit and it is common practice to use the millisievert (mSv). 1mSv = 10^{-3}SV. (In terms of the rem, the older unit of dose equivalent, 1Sv = 100 rem.

URANIUM

A radioactive element with two isotopes which are fissile (uranium-235 and uranium-233) and two which are fertile (uranium-238 and uranium-234). Uranium is the basic raw material of nuclear energy.

LECTURE 4

DESCRIPTION AND OPERATION OF GATRI

M. IZARD

AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

DESCRIPTION AND OPERATION OF GATRI

M. E. IZARD
(1985)

CONTENTS

1. INTRODUCTION

The gamma technology research irradiator (GATRI) is a cobalt-60 gamma irradiator suitable for research and development projects and small scale industrial applications. Cobalt rods and discs can be arranged as a line or plaque source and dose rates may be selected by changing the source load, source to target distance, or by placing shielding between the source and target.

The cobalt source is stored under water when not in use and is elevated by remote control into the shielded irradiation chamber. Interlocks and controls are installed to ensure safe operation and override keys of restricted access are provided to enable maintenance and adjustments to be carried out.

GATRI is located in a separate building adjacent to the isotope production complex at the south-western end of the research establishment.

2. GENERAL DESCRIPTION

The irradiation chamber is a 3 m x 4 m room surrounded by concrete walls and roof, each 1.5 m thick. A doorway 1.3 m wide by 1.4 m high in the Northern shield wall provides access to the chamber. The door is closed by a motorised, 1.5 m thick, stepped concrete shield door mounted on four traction wheels that run on guide rails set in the floor of the external operations area. Shielded ducts in the eastern and southern walls provide access for services and instrumentation cables. Controls to operate the shield door and hoist are housed in a console on the northern wall outside the irradiation chamber adjacent to the access door.

2.1 Cobalt Sources

The plaque source comprises a number of stainless-steel encapsulated cobalt-60 rods 150 mm long x 8 mm diameter and discs 2 mm thick x 20 mm diameter. Each rod and set of five discs is further encapsulated in a screw-capped stainless steel source holder; up to five holders containing sources or spacers may be housed in each of twenty 1 m long tubular retainers mounted in a 1 m^2 rack. The maximum permissible source load is 3.7 PBq.

2.2 Source Hoist Assembly

The source hoist assembly consists of the following components:

(i) Hoist carriage comprising an upper hanging beam and a lower support beam.
(ii) Guide tubes.
(iii) Drive chains, sprockets and pulleys.
(iv) Top support beams and brackets.
(v) Bottom mounting beam and brackets.

The radiation source rack is held between the upper hanging beam and the lower support beam of the hoist carriage which moves vertically between two polished stainless steel guide tubes extending from the floor of the shield water tank to the ceiling of the irradiation chamber. The hoist carriage is held in position between the guide tubes by a sleeve at the end of each beam which carries two sets of rollers spaced equi-angularly at its upper and lower ends. The hoist carriage is raised and lowered by means of stainless steel roller chains attached to each end of the hanging beam. The chains are driven by a series of drive shafts from a motorised gearbox or handcrank outside the irradiation chamber. The source rack and lower support beam can be detached from the driven hanging beam by operating the emergency source release. A solenoid operated pawl ratchet controls the hoist mechanism and is in turn controlled by a safety interlock circuit, designed to prevent the door from being opened when the hoist is raised, and to lower the source in the event of a power failure.

2.3 Ventilation

The irradiation chamber is ventilated by a 250 mm axial blower fan mounted in an exhaust duct on the roof. An internal duct extends in a curve down through the south shield wall and enters the chamber in the south-east corner through the ceiling.

2.4 Shield Water System

Recirculated demineralised water is used as a radiation shield when the source is not exposed in the irradiation chamber.

2.4.1 Source storage tank

The radiation source is stored under 5 m of demineralised water in a 1.9 m diameter stainless steel tank recessed into the floor of the irradiation chamber.

The water level in the tank is monitored, at depths of 4.4 m (level 1) and 3.8 m (level 2), a diaphragm pressure switch connected via a fixed stainless steel air line to an air bell about 2.5 m below the lip of the tank.

2.4.2 Shield water circulation

An AJAX type CA3/4 centrifugal pump draws shield water from the bottom of the storage tank and circulates it through a Cuno pre-treatment filter and a Permutit Mixed Bed Deminrolit Type MB 12 water treatment plant at 1350 L h^{-1}.

2.5 Television Monitor

When the source is raised, the irradiation chamber can be observed by closed circuit television. A National WV-230N TV camera is mounted at the north-east corner of the irradiation chamber in a lead shielded container fitted with a pneumatically operated lead shutter to protect the lens from radiation. Three small lamps in front of the camera lens provide auxiliary lighting, thus ensuring that the camera is not subjected to sudden changes of light intensity when the shutter is operated.

2.6 Tank Covers and Safety Screens

Two semi-circular platforms partly cover the storage tank with sufficient clearance to ensure that source elevation is unhindered. A wire mesh screen hinged along the diameter of each cover can be raised to prevent material being irradiated from obstructing the source mechanism.

2.7 Radiation Detectors

Two radiation detectors are incorporated in the control circuitry to monitor radiation levels in the irradiation chamber and in the shield water. A third detector mounted on the northern external wall of the irradiation chamber monitors radiation in the operations area.

2.7.1 Irradiation chamber

Radiation in the irradiation chamber is detected by a Centronic 100 type IG 21 ionisation chamber mounted on the ceiling directly above the storage tank. Output is displayed on a cell radiation meter on the control console. A small cobalt-60 source adjacent to the detector provides a threshold dose rate, so that if the ion chamber fails the radiation alarm will be activated (see section 3.1).

2.7.2 Shield water

Activity in the shield water is detected by a Geiger-Muller (GM) tube fixed to the ion exchange column of the water treatment plant. Output is displayed on a water activity meter on the control console. A small cobalt-60 reference source in the GM tube container provides a low threshold dose rate so that if the detector fails a radiation warning is produced (see section 3.2).

2.8 Source Hoist Control

Elevation of the source hoist carriage is controlled by a solenoid-operated ratchet which must be activated before the hoist can be raised. Power can only be supplied to the hoist raise mechanism if the ON/OFF operational key 032 is in place and turned on, the chamber door closed, with the door bolt in, the ventilation fan on, the shield water above level 1, no alarms registered, the manual drive handle removed, and restricted key R54 not in use.

2.9 Door Control

Most door controls are located on the control console, however a remote switch inside the irradiation chamber must be actuated before power is available to the 'door close' switches. A weight-switch under the eastern guide rail in the irradiation chamber doorway is actuated as the door is closed and a manually operated door bolt switch at floor level must be engaged before a 'door closed' signal is given and power supplied to the hoist control circuits.

2.10 Emergency Source Release

In the event of a mechanical failure in the hoist mechanism as the source is being raised or lowered, an emergency source release can be used to free the source from the hoist and allow it to drop freely into the storage tank. The emergency source release mechanism is housed in a vertical duct on the external eastern wall of the irradiation cell. It is operated by pulling down on the weighted handle attached to the lower pulley.

3. ALARMS AND WARNINGS

A number of alarms and warnings are incorporated into the control circuits to indicate abnormal or hazardous conditions. There are two levels of hazard notification. If conditions are dangerous or potentially dangerous to the operator, large red flashing lamps and klaxons are activated and the Lucas Heights site emergency office is signalled. Less hazardous but abnormal conditions are indicated by small amber flashing lights and sonalerts.

Small lamp-annunciators on the control console indicate the condition responsible for activating the alarm klaxons or the warning lights. These indicators are automatically cancelled when the fault is rectified.

3.1 Radiation Alarm

The radiation alarm will be activated if an attempt is made to open the door when the source is raised or if the door is open and radiation in the chamber exceeds 2 $mSv\ h^{-1}$ as a result of total or partial loss of shield water. An operator trapped in the chamber can activate the alarm by means of a chain-operated switch on the east wall of the chamber. This device also prevents raising of the source. Removal of key R52 from its normal position in the control console will also activate the alarm.

3.2 Radiation Warnings

Radiation warnings are given to indicate increased levels of radioactivity in the shield water. These conditions are not serious hazards but require some maintenance operation, such as renewal of the Mixed Bed Deminrolit resin or the Cuno pre-treatment filter. The first warning is a flashing amber lamp when activity exceeds 200 $\mu Sv\ h^{-1}$. An audio signal from a sonalert can be muted by a switch on the control console. This signal will be given with the visual warning above 400 $\mu Sv^{-1}h$ irrespective of the position of the muting switch.

3.3 Water Level Warnings

Visual warning of incorrect water level is given by the lamp-annunciators at level 1 (Section 2.4). Audio warning by sonalert is also given and may be cancelled by the muting switch on the control console. When an alarm is given at level 2, the sonalert cannot be cancelled by the muting switch.

4. ROUTINE OPERATIONS

Routine operations such as opening and closing the shield door, elevating and lowering the source and recirculating the shield water are initiated at the control console, but their execution is controlled by the safety interlocks.

4.1 Irradiation Chamber

The principal routine operations involving the irradiation chamber are raising and lowering of the source and movement of the shield door.

4.1.1 Closing shield door

Status: the door is open, there are no alarms, and the cell is unoccupied.

(i) Enter the cell and push the red button switch on the internal chamber wall opposite the doorway. Verify that the cell is unoccupied before closing the shield door.

(ii) Within 30 s, return to the control console and hold down the red 'close enable' and MS2 switches simultaneously.

(iii) Hold down the 'close enable' switch when the door stops at its first limit, release MS2 and hold down MS1 to close the door completely.

NOTE: If the 'door enable' switch is released during closing, the door will stop and may have to be reopened before steps (i) to (iii) can be repeated.

4.1.2 Raising source

Status: the door is closed, there are no alarms.

(i) Move the door bolt to 'in'.

(ii) Hold down either the red (fast) or the black (slow) 'raise' switch.

NOTE: The hoist will stop automatically at the preset limit. It may also be stopped at any height by releasing the 'raise' switch and restarted by holding down either 'raise' switch.

4.1.3 Lowering source

Status: the door is closed, there are no alarms.

(i) Hold down either the white (fast) or the green (slow) 'lower' switch.

NOTE: The hoist will stop automatically at the bottom of the storage tank. It may also be stopped at any position by releasing the 'lower' switch and restarted by holding down either 'lower' switch.

4.1.4 Opening shield door

Status: The door is closed, there are no alarms and the source is down.

(i) Move the door bolt lever to 'out'; a lighted annunciator on the console shows 'door bolt clear'.

(ii) Wait approximately 5 s for hoist relays to disengage; this is signified by a 'clunk' from the hoist drive system.

(iii) Hold down the red 'open' switch adjacent to the door open annunciators.

(iv) Door movement may be stopped by releasing the 'open' switch and restarted from any position. A travel limit switch will cut off power to the motor when the door is fully open.

LECTURE 5

IRRADIATION PROCEDURES & RADIATION DOSIMETRY

M. IZARD

AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

IRRADIATION PROCEDURES AND RADIATION DOSIMETRY

M. E. IZARD
(1985)

INTRODUCTION

The radioactive decay of Co^{60} results in the production of very energetic and highly penetrating gamma rays which will pass through matter causing ionizations as they lose energy. Numerous effects are produced by the absorption of ionizing energy depending on the material being treated and the amount of radiation absorbed. Typical effects in food include extension of shelf life and delayed ripening.

For gamma rays having energy greater than 200 KeV the predominant absorption process is Compton scattering. This occurs when the incident gamma ray or photon interacts with the orbital electrons of an atom. Part of the photon energy is transferred to the orbital electron which is ejected from the atom and the photon is deflected with reduced energy. The degraded photon then goes on to produce more of these ionizations. The minimum photon energy for gamma radiation to interact with the nucleus to produce radioactivity in the target material is at least 1.7 MeV. Cobalt 60 emits a 0.31 MeV beta ray and gamma rays with energies of 1.1 and 1.3 MeV and does not therefore induce radioactivity in or contaminate the irradiated material in any way.

The safe use of ionizing energy in any application necessitates a properly designed and constructed irradiation facility and extensive process controls to monitor safety and performance.

IRRADIATOR DESIGN

The design of an irradiation facility must provide a safe source storage area, a safe irradiation area, safety controls and interlocks to prevent accidental exposure of personnel, some form of product handling system within the irradiation chamber and storage facilities to separate irradiated and unirradiated material.

Operational parameters to be considered include size of the radiation source and its form, material throughput (the rate at which material can be treated), radiation doses required, uniformity of the radiation field and over-dose ratio (the ratio of maximum to minimum dose delivered to the target material). The irradiator should deliver to a range of target materials as uniform a dose distribution as possible in the shortest practicable time.

Radiation doses encountered in radiation processing range from 0.05 kGy to 1 MGy and can be divided into a number of dose levels. For example very low doses from 0.05 to 0.15 kGy prevent sprouting in potatoes, onions and garlic. Fruits, vegetables and cereals can be disinfested by doses up to 1 kGy. Doses from 1 to 5 kGy will pasteurize various foods by reducing the number of microorganisms present. Higher doses will sterilize foods and medical products and doses 100 Ky and higher can produce cross-linking in polymers.

Although most early commercial irradiators were designed for a specific purpose such as the sterilization of medical products and were as a result limited in their usefulness for other applications, there is now a developing demand for multi-purpose irradiators that can be conveniently operated at low, medium and high doses.

Four types of irradiator are in use around the world today, and they can be classified according to their irradiation and storage compartments.

Source Storage	Irradiation Chamber
Deep water tank	Source raised into concrete shielded cell
Deep water tank	Material lowered in watertight containers into storage tank
Concrete shielded chamber	Source transferred into adjacent concrete shielded chamber
Lead shielded container	Lead shielded cavity in the same container

RADIATION SOURCES

Two radioisotopes are currently in use in radiation processing plants. They are cobalt-60 as the metal and cesium-137 as recrystallized cesium chloride.

A comparison of their properties is shown below:-

	Co-60	Cs-137
Radiation energy	1.17 and 1.33 MeV	0.66 MeV
Half life	5.66y	26.99y
Specific activity	50 - 100 Ci g^{-1}	24 Ci g^{-1}
Annual replenishment	12.5%	2.3%

The more commonly used iosotpe is cobalt-60 produced by neutron irradiation of pure metallic cobalt-59. The cobalt for use in irradiation facilities is usually in the form of rods or discs doubly encapsulated in stainless steel source holders containing several thousand curies.

The half-life of cobalt-60 is 5.66 years meaning its activity decreases by 50% over each 5.66 y period or by approximately 1% per month. Annual replenishment of 12.5% of the cobalt will return the source to its original activity.

GAMMA TECHNOLOGY RESEARCH IRRADIATOR (GATRI)

GATRI consists of a 3 m x 4 m irradiation chamber shielded by 1.5 m concrete walls, roof and access door. The source is a 1 m x 1 m plaque containing 3 PBq of cobalt 60 in the form of rods and discs housed in twenty 1 m long vertical source holders. Various safety interlocks prevent raising of the source when the irradiation chamber door is open.

Material to be irradiated is placed on benches or turntables located on isodose curves around the source. The benches and turntables can be positioned between 300 mm and 1500 mm from the source to produce the required dose rate.

Very low dose rates can be obtained by irradiating the target material behind lead brick walls.

DOSE RATE DISTRIBUTION IN AN IRRADIATOR

Uniformity of dose rate distribution within the irradiation chamber will depend on source configuration and source to target separation.

Dose rate distribution will be symetrical about point sources and will decrease exponentially with distance from the source according to the inverse square law:

$$\text{Dose }(d2) = \text{Dose }(d1)/(d1/d2)^2$$

The dose rate distribution around line and plaque sources depends on the source to target distance and distribution of activity within the source. The inverse square law may not hold for large sources operated with small source to target distances.

DOSE DISTRIBUTION WITHIN THE PRODUCT

Depth dose rate distribution or degree of uniformity within a rectangular target depends on source to target geometry, target thickness and orientation. Maximum practicable target thickness i.e. the dimension normal to the plane of the source, depends on the allowable variation in the ratio of maximum to minimum dose to be delivered to the product, which in turn depends on target density and atomic number of the absorbing material.

If a target is irradiated in a fixed position then the maximum dose rate will always occur on the outside of the target in that plane nearest the source i.e. the front face, and the minimum dose rate will be on the rear face i.e. that plane farthest from the source. The dose rate at the mid plane of the target will depend on the thickness and density of the target and to a lesser extent on dose build-up within the target.

Depth dose variation can be minimized by irradiating the target at greater source to target separation or by employing two sided or multi-sided irradiations.

The total dose is generally delivered in two equal irradiation periods. After the first the material is rotated through 180 degrees and re-irradiated. Some further improvement in dose uniformity may be gained by irradiating from more than two sides or by inverting and rotating the package halfway through the irradiation.

In a fixed position irradiator packages are usually aligned to present minimum thickness to the source to improve depth dose uniformity.

Lateral and vertical dose uniformity within the target depend on the alignment of the target with respect to the source. They can be improved by source overlap, by increasing the horizontal and vertical dimensions of the source so that it overlaps the product in both directions.

Lateral and vertical dose uniformity may also be improved by utilizing product overlap, that is by moving the product along the X and/or Y axis parallel to the source plaque during the irradiation.

If the target is rotated continually during irradiation the maximum dose rate is at the surface and minimum dose rate is at the centre of the target for a target of any size and density.

In any irradiator, as the source to target distance increases, depth dose uniformity and vertical and lateral dose uniformity improve.

IRRADIATION PROCEDURES

Three product parameters determine the irradiating conditions for most material, they are:-

(i) dose required,
(ii) density of the package and
(iii) package dimensions.

Once these are determined a location in the irradiation chamber can be chosen at which there is a suitable dose rate to allow a convenient irradiation period with minimum overdose. Similar packages should be irradiated on isodose curves around the source to achieve dose uniformity throughout the package stack.

In a fixed position batch irradiator like GATRI depth dose variations are minimized by employing two side irradiation of the product.

Extensive radiation dosimetry is necessary to calibrate the facility, to set irradiation parameters and to measure absorbed dose in irradiated material.

Inventory control is critical in a radiation processing plant as there is unlikely to be any visible changes following irradiation. So that irradiated and unirradiated material cannot be mixed a coloured go-no-go dosimeter should be attached to each package before irradiation. A colour change will indicate that the package has been processed.

MEASUREMENT OF RADIATION DOSE

The radiation dose is the amount of energy absorbed by the target during irradiation, expressed as energy per unit mass e.g. $J\ Kg^{-1}$ and for any gamma ray depends on the energy of the incident gamma ray and the atomic number of the absorber. For example an exposure to $2.5\ C\ Kg^{-1}$ of gamma rays with energy of 1.602×10^{-14}J will deposit $87\ J\ Kg^{-1}$ in air and $100\ J\ Kg^{-1}$ in water.

The quantitative measurement of absorbed dose is termed radiation dosimetry and it is essential for calibration of an irradiation facility and as a process control during the irradiation treatment.

The absolute methods for measuring absorbed radiation dose are calorimetric determination of heat produced or measurement of the number of ions produced in a gas under standard conditions. However because of practical difficulties in using these methods, secondary dosimeter systems are more commonly used. Chemical systems used at AAEC for most applications are the Fricke ferrous sulphate and the ceric/cerous dosimeters. Perspex dosimeters are also used for dose verification during some commercial irradiations.

A primary dosemeter used for calibration of the GATRI irradiation facility is the Baldwin-Farmer ionization chamber. This instrument measures the ionization produced in a small detector chamber that can be easily positioned anywhere in the irradiation cell. Radiation induced ionization charges a capacitor, one terminal of which is connected to an electrometer null detector. As the capacitor is charged the potential at the other terminal is adjusted to restore null balance and the potential required is indicated on a meter as radiation dose.

The performance of chemical dosemeters depends on reaction between the added solute ions and reactive species formed by irradiation in the surrounding water. Radiolysis products formed during irradiation of water include solvated electrons, various radicals as well as hydrogen, hydrogen ions and hydrogen peroxide.

A solute may react with any of these short lived and very reactive radiolysis products to form a more stable measurable product

Solute + solvated electron → Stable Product

(OH^-)

(H)

If the concentration of the final product is proportional to the radiation dose absorbed and can be conveniently measured the system may be suitable for use as a radiation dosimeter.

The short lived reactive radicals produced during irradiation act as reducing and oxidizing agents towards solute ions. A hydroxyl radical can accept electrons i.e. act as an oxidizing agent

$$OH + \text{electron} \rightarrow OH^-$$

and a hydrogen atom can donate electrons as a reducing agent

$$H + H_2O \rightarrow H_3O^+ + \text{electron}$$

In the case of the Fricke dosimeter each water molecule decomposed by radiation can oxidize four ferrous ions. A hydroxyl radical can oxidize a ferrous ion and the remaining hydrogen atom can react with oxygen to produce the HO radical which causes the oxidation of another three ferrous ions.

$$Fe^{2+} + OH \rightarrow Fe^{3+} + OH^-$$

$$H + O_2 \rightarrow HO_2$$

$$Fe^{2+} + HO_2 + H^+ \rightarrow H_2O_2 + Fe^{3+}$$

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH + OH^-$$

$$Fe^{2+} + OH \rightarrow Fe^{3+} + OH^-$$

In the ceric dosimeter a ceric ion is reduced by a hydrogen atom

$$Ce^{4+} + H \rightarrow H^+ + Ce^{3+}$$

and a cerous ion is oxidized in a back reaction by a hydroxyl radical

$$Ce^{3+} + {\cdot}OH \rightarrow Ce^{4+} + OH^-$$

A difference in reaction rates favours the ceric to cerous conversion so there is a net increase in the concentration of cerous ions.

The concentration of stable product is dependent on the radiation dose and is defined as a G value or the number of solute molecules transformed per 16.02 attojoule (100 eV) of absorbed energy.

The dose range of the dosimeter depends on the G value. The minimum dose must be high enough to produce sufficient product for measurement and the maximum dose is limited by the supply of reacting species.

The Fricke ferrous sulphate dosimeter is based on spectrophotometric determination of the concentration of the ferric ions produced during irradiation. The dose range is 50 to 400 Gy and response is independent of dose rate between 1 and 400 Gy s^{-1}. It is used extensively to set the irradiation parameters in GATRI but because of its limited dose range it is not suitable for verification of doses used in routine commercial irradiations such as ionizing energy treatment of food or sterilization of medical products.

The ceric/cerous dosimeter is based on the production of cerous ions during irradiation of ceric sulphate and may be prepared at various concentrations to measure doses from 10 to 10^6Gy, the actual range being dependent on the concentration of ceric ions in the dosimeter before irradiation. The change in concentration of ceric ions following irradiation can be determined spectrophotometrically or by differential potentiometry in a simple electrochemical cell.

The respective G values are approximately 15.6 for ferric ion and 2.5 for cerous ion. Because the rate of loss of ceric ion per unit of absorbed dose is so much lower than that of ferrous ion, the ceric dosimeter can be irradiated to much higher doses without exhausting the dosimeter.

Perspex (polymethylmethacrylate, PMMA) in the form of small thin (1-3 mm) strips is used as a dosimeter for doses between 5 and 50 kGy. When irradiated, degradation products of the polymer form in the matrix and their concentration can be measured spectrophometrically at 300 to 320 nm. Red perspex contains a dye, which reacts with polymer radicals to produce absorbance changes measured spectrophotometrically between 600 to 650 nm. Because of variations in radiation response and environmental conditions the absorbance changes in these dosimeters following irradiation, must be calibrated against other dosimeters such as the Fricke or ceric/cerous dosimeter.

Radiation dosimetry is absolutely essential for the proper calibration and operation of an irradiation plant. Because the radioactive decay of cobalt is constant, dose rates within the irradiation chamber can be estimated accurately any time after the initial calibration. However the variability of products, and packages to be treated and the range of doses and dose rates required demand frequent evaluation of absorbed dose by some straight forward method to ensure that the treatment is as required by the customer and regulatory authorities.

LECTURE 6

POSTHARVEST STORAGE OF FRUIT & VEGETABLES

N. WADE

AUSTRALIAN SCHOOL OF
NUCLEAR TECHNOLOGY

POSTHARVEST STORAGE OF FRUIT AND VEGETABLES

N.L. WADE

Department of Agriculture,
New South Wales.

INTRODUCTION

Fruit and vegetables are living organs which have been detached from the plant. These organs include fruits, stem tubers, swollen taproots, swollen hypocotyls, bulbs, stems, axillary buds, flower buds, swollen infloresceces, main buds, petioles, leaf blades and swollen leaf bases. Because these organs are alive they respire and transpire, evolving carbon dioxide, water vapour, and heat, whilst consuming oxygen. Plant tissues also produce ethylene, a biologically active substance which induces ripening and senescence. Detached plant organs are subject to mechanical and chemical injury, and to physiological and pathological diseases and disorders.

The quality of fresh produce depends in part upon harvesting at the correct stage of development or maturity. A mature commodity is one which at the time of harvest already possesses, or has the potential to acquire, desirable eating quality. Some commodities, like green leafy vegetables, storage tubers, and citrus fruits can be ready to eat when harvested, and will not improve after harvest. Other commodities, such as bananas and tomatoes, can be picked mature but unripe, and they are not ready for consumption until the ripening process has taken place.

Ripening refers to the changes in texture, sweetness, colour and aroma which occur in some fruits, and should not be confused with maturity, which refers to the stage of development. Fruits may be divided into two classes according to their ripening behaviour. Climacteric fruits undergo an abrupt and dramatic ripening process which transforms them from a firm, green and often starchy fruit into a soft, coloured, sweet and aromatic product. Examples of climacteric fruits are apple, apricot, avocado, banana, fig, mango, muskmelon, passionfruit, peach, pear, plantain, plum and tomato. Non-climacteric fruits do not undergo an abrupt ripening change, but merely mature slowly on the tree or vine. Examples of non-climacteric fruits are cherry, cucumber, grape, grapefruit, lemon, pineapple, strawberry, orange, tamarillo.

DISEASES

1. Causes of disease

Fruit and vegetables are subject to disease caused by fungal and bacterial pathogens after harvest. Some postharvest diseases begin as field infections. These infections merely continue developing after harvest, causing wastage in the marketplace. Most postharvest diseases are caused by fungal spores or bacterial cells which are resident on the commodity at harvest time, or contaminate the commodity when unclean packing equipment and packages are used. Infection occurs after harvest, when opportunities arise for these resident spores and cells to penetrate the external cuticle of the fruit or vegetable. Important predisposing factors to infection are cuts, bruises, abrasions or punctures inflicted on the commodity during harvest and postharvest handling. Another factor is the common practice of leaving the produce lying in the sun after harvest.

A third kind of postharvest disease is caused by latent infection. This occurs when spores of a pathogen alight on the surface of the commodity in the field, and the spores germinate and commence the infection process. Once an infection site is established, however, the pathogen becomes quiescent and the infection is said to be latent. When the commodity is harvested and begins to ripen, the pathogen resumes growth and visible disease lesions form. This type of disease is common in tropical fruit such as the banana, mango, and papaya. Anthracnose disease of these fruits arises from latent infection.

2. Examples of disease

A few examples of important diseases include blue mould of apples and pears caused by the fungus *Penicillium expansum*, anthracnose of banana caused by the fungus *Colletotrichum musae*, green mould of citrus caused by the fungus *Penicillium digitatum*, soft rot of stone and berry fruits caused by the fungus *Rhizopus stolonifer*, and bacterial soft rot of potato, tomato and leafy vegetables caused by *Erwinia carotovora*.

3. Control of disease

Careful handling practices are most important in disease prevention. Mechanical damage of the produce must be avoided, and it should be kept as cool as possible and out of the sun. Refrigeration is a useful control measure, because it slows down senescence and ripening of the produce and the growth of many pathogens. High humidity favours the germination of fungal spores and is often essential for infection to occur. Control of humidity is, therefore, important. Washing produce with water provides the moisture needed for infection, and may also contaminate the produce if the water is not clean. Wash water should be clean or treated with chlorine, and washed produce dried or treated with a fungicide or bactericide.

Postharvest fungicide treatments have proven to be very effective in disease control if used correctly. Fungicides may be applied by spraying the produce as it is being rotated by a set of rollers, or by dipping the produce in a tank or bath of fungicide preparation. The treated produce is allowed to drain, and may then be packed in the usual way. Many fungicides act by inhibiting spore germination or growth of the newly-germinated sporeling. Such fungicides must be applied before infection begins if they are to be effective. Produce should be treated with fungicide as soon as possible after harvest, and no later than 24 hours after harvest.

Some examples of postharvest fungicides are benomyl, sec-butylamine, dichloran, diphenyl, guazatine, iprodione, imazalil, sodium ortho-phenylphenate and thiabendazole. To be suitable for postharvest use a chemical must satisfy stringent requirements regarding its safety as a food additive.

INSECT PESTS

Insects pests such as the tephritid fruit flies represent a postharvest problem in fruits. Eggs laid in the fruit before harvest subsequently hatch. The larvae cause wastage of the fruit. Quarantine barriers erected against produce originating from an area where such insect pests occur disrupt trade.

Measures currently used to disinfest produce of insect pests are fumigation with gaseous sterilants such as ethylene dibromide, storage at low temperature, and brief heat treatments. A difficulty with disinfestation treatments is that where they are required for quarantine purposes, they must not just curtail wastage but completely eradicate the pest. The severe treatments required to do this may be phytotoxic.

PHYSIOLOGICAL DISORDERS

Physiological disorders are a type of tissue injury which is not caused by pathogens or mechanical damage. These disorders may develop in response to an adverse environment, especially temperature, or to a nutritional deficiency.

One of the best-studied disorders of tropical produce is chilling injury. Chilling injury should not be confused with freezing injury, since chilling occurs several degrees above the freezing point of a tissue. Chilling injury is caused by a physical change in state of cellular membranes which leads to abnormal metabolism. Susceptibility to chilling limits the use which can be made of refrigeration in storing tropical produce.

A number of fruit and vegetable disorders are associated with calcium deficiency or unavailability. Examples are bitter pit of apple, end spot of avocado, internal tipburn of cabbage and blossom-end rot of tomato. Considerable success has been achieved in preventing the bitter pit disorder of apple by treating the fruit with calcium chloride solutions after harvest and before storage.

TEMPERATURE MANAGEMENT

1. Introduction

Temperature is a very important factor in fruit and vegetable handling. As the temperature increases so does the metabolic activity of the produce, and the onset and development of ripening and aging are hastened. High temperatures favour infection and disease development. Water loss increases at higher temperatures, resulting in weight loss and shrivelling. Careful mangement of produce temperature is, therefore, an important technique of post-harvest handling.

2. Optimum handling temperature

Many commodities will keep best at a temperature which is just above their freezing point, and storage at 0°C is often recommended for crops which are adapted to cool growing conditions. Warm-climate or summer crops such as banana, mango, papaya, cucumber, tomato and capsicum are liable to suffer chilling injury at temperatures below about 10-15°C, and so they should not be stored at lower temperatures. The symptoms of chilling injury include failure to ripen properly, surface pitting, tissue discolouration, water-soaking and disintegration of tissue, and invasion of tissue by weakly pathogenic organisms.

3. Cooling rate

It is important to cool produce quickly. Hot produce loses shelf-life rapidly. Stacks of packaged produce cool very slowly, and methods of cooling are needed which improve heat exchange. Pressure-cooling is such a technique. Cold air is forced into each package or bin, and flows around each piece of produce. A fan is used to achieve this airflow. Rather more expensive techniques use cold water (hydrocooling) or latent heat loss (vacuum cooling).

4. Protection from the sun

Exposure to the sun reduces both shelf-life and quality. It is most important to keep freshly-picked produce in shade. Trailers and trucks used to carry produce should have protective canopies.

5. Prevention of self heating

Some commodities, and in particular vegetables such as peas, asparagus, sweet corn, and also mushrooms, have very high rates of respiration. When such commodities are built into stacks, the heat of respiration can actually cause large increases in flesh temperature. Such commodities should be stacked loosely with adequate ventilation gaps, and cooled quickly.

6. Evaporative cooling

Evaporatively-cooled air is an excellent and economical medium for produce cooling. It can be obtained easily by establishing an airflow through a moist, porous surface. Evaporative cooling can sometimes be used during transport by wetting the produce and allowing the airflow around the moving vehicle flow through the load.

7. Mechanical refrigeration and ice

Mechanical refrigeration is a highly effective though expensive way of cooling produce. Care is needed in designing the refrigeration plant so that it will have sufficient cooling capacity to absorb heat evolved by the produce, whilst maintaining a high relative humidity in the store. The storage room itself must be well-insulated.

Ice can be useful in produce cooling, especially when used in packages to keep produce cool during transit. A refrigeration plant is required to manufacture the ice.

ATMOSPHERE CONTROL

Useful storage responses can be obtained by modifying the atmosphere in which fruit and vegetables are stored. Lowering the oxygen concentration to about 2-5% interferes with the ethylene ripening system and retards ripening and aging of a number of fruits and vegetables. Raising the carbon dioxide concentration to about 5-20% can enhance this effect, but care must be taken since many commodities are easily injured by carbon dioxide. It is sometimes also necessary to remove ethylene from the storage atmosphere.

Controlled atmosphere storage is used commercially for the storage of apples and pears, so as to spread the marketing of these crops through the year. Other fruits and vegetables respond favourably to this technique, but are not stored commercially for economic reasons. The banana is an example of another fruit which responds very well to controlled atmospheres.

Controlled atmospheres are obtained by placing the produce in a gas-tight storage room. The desired atmosphere can be generated either by the respiration of the produce itself, or by the operation of a generator, which may be a gas-burner. The composition of the storage atmosphere must be regularly analysed, and adjustments made by admitting outside air or circulating the room contents through a carbon dioxide scrubber.

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LECTURE 7

IONISING ENERGY TREATMENT OF FRESH FRUIT

C. RIGNEY

IONISING ENERGY TREATMENT OF FRESH FRUIT

C.J. Rigney
N.S.W. Department of Agriculture
Gosford Horticultural Postharvest Laboratory

For the ionising energy treatment of fresh fruit to be economically and socially acceptable it must perform a function which is socially demanded, or at least attractive, in a superior manner to alternative treatments. The superiority of this treatment may not only be due to direct economic factors, but rather to its ability to perform specific functions without causing any detrimental effect on the commodity, or raising doubts about the wholesomeness or safety of the product for the consumer.

Specifically the main purpose of the ionising energy treatment of fresh fruit may be one or more of the following:

1. The extension of shelf life of the commodity due to a direct physiological effect on the particular product;
2. The extension of shelf life of the commodity due to a reduction in the development of moulds and rots which would normally render the product worthless;
3. The killing of insect pests of quarantine significance, to allow for normal marketing of fresh fruit without the risk of introducing insect pests to previously pest-free areas.

Extension of Shelf Life.

The physiological extension of shelf life of fresh fruit is associated with a retardation of ripening and senescence of the fruit. This is particularly relevant for climactric fruit such as bananas, mangoes and pawpaws, which undergo a significant postharvest rise in respiration and ethylene production associated with a direct senescence metabolism. In the case of such fruit the physiological shelf life can be significantly extended by low dose irradiation treatments. As an example, the treatment of bananas with between 250 to 500 Gy can increase the shelf life of the fruit from 25 to 45 days, in the absence of exogenous ethylene. This irradiation treatment apparently reduces the sensitivity of the fruit to ethylene, so that up to 24 hours extra exposure to ethylene is required for uniform ripening (Maxie *et al.*, 1968). The eating quality of these fruit is not effected by such a treatment.

In general the irradiation of mangoes with doses between 250 and 600 Gy increases the shelf life of the fruit by delaying senescence. The degree of shelf life extension, as well as the maximum tolerable dose, varies between cultivars and locality. Studies carried out to date indicate that mangoes in India can tolerate 750 Gy, in Florida 100 Gy, in Hawaii 1000 Gy (Akamine and Moy, 1983) and common mangoes from north Queensland can tolerate 600 Gy without injury. "Nan Klang Wan" mangoes were recently treated in Thailand to a dose of 750 Gy, which delayed colour development, but had no adverse effect on fruit quality (Buangsuaron and Sukasen, 1985). An extension of shelf life of 7-9 days was seen with the north Queensland fruit treated with 600 Gy. Kensington Pride mangoes from northern N.S.W. were found to be more tolerant of irradiation than were the Common mangoes. This difference in radiation tolerance may be associated with the difference in fibre content, which is significantly higher in the Commons than in the commercial Kensington cultivars.

Extensive research over the past 20 years in Hawaii has indicated that ripening and senescence of pawpaws can be retarded by a dose of 750 Gy. In combination with a hot water dip at 49°C for 20 min, this irradiation treatment resulted in a further 3-4 days extension of shelf life. The research involved in the development of this combination treatment for pawpaws is of general significance for many fruits, since it indicates a highly suitable research approach. Much of this research was carried out by Akamine, Wong, Goo and Moy at the University of Hawaii and recently reviewed by Akamine and Moy (1983). The first of these studies indicated that treatment of pawpaws with more than 1 K Gy caused some surface scalding and 2 K Gy resulted in poor colour development of the ripe fruit. Doses of 4 and 5 K Gy caused poor flavour and aroma development, and tissue breakdown respectively. This data therefore indicated that a dose of 1 K Gy would be the maximum tolerable dose for pawpaws in Hawaii. However on ripening and storage, fruit treated with 1 k Gy were significantly softer than similar fruit treated with 750 Gy. It was therefore concluded that 750 Gy would be optimum for shelf life extension of these fruit.

The physiological effects of gamma-radiation on fruit is far from clear. Recent studies in China (Xu Zi-cheng, 1985) indicated that irradiation of apples with 500 Gy would extend the shelf-life of the fruit stored at 2°C to 9 months. Kovacs _et_ _al_. (1985) suggested an interaction of irradiation and calcium metabolism in apples. However this interaction is unclear, especially since our recent studies with Jonathon and Granny Smith apples (Rigney _et_ _al_. 1985) indicated that iradiation to 600 Gy did not alter the rate of softening of the fruit, which could be expected if there was a major change in calcium metabolism.

To control organisms causing postharvest decay of pawpaws a dose of 6 K Gy is required. Since this dose was known to result in significant tissue breakdown a combination of hot water treatment and irradiation was examined; it had been previously found that a single hot water dip could reduce pawpaw decay. This combination treatment of 49°C for 20 minutes followed by a 750 Gy dose controlled postharvest storage decay and extended the shelf life. However, subsequent storage at 13°C, the normally optimum storage temperature for pawpaws, resulted in surface scald development. Raising the storage temperature to 16°C eliminated this scald problem. This series of experiments indicates that many factors may contribute to an optimum irratiation regime, and one should not be put off by an initially poor experimental result. The optimum storage temperature for irradiated fruit may be different from that normally used for storage of the non-irradiated product.

In the case of non-climacteric fruit, which do not undergo a significant postharvest rise in respiration, no physiological extension of shelf life could be anticipated. Such fruit include oranges and strawberries. Treatment of oranges with more than 1 K Gy may cause some peel injury, although organoleptic differences are not apparent with less than 3 K Gy (Grierson and Dennison, 1965). This treatment causes no change in soluble solids or citric acid content of the juice, and the ascorbic acid level is only slightly reduced.

Although there may be no direct physiological benefits resulting from the treatment of strawberries by ionising energy, an extension of shelf life does result from treatment of the fruit with 2 K Gy. This is due to the control of spoilage organisms, particularly transit rots such as Botrytis cinerea. This organism, which is responsible for the major postharvest losses of strawberries, can be retarded by a 2 K Gy dose. Strawberries thus treated and stored at 5°C can have a shelf life in excess of 14 days (Sommer and Fortlage, 1966).

Insect Disinfestation

A major benefit of the ionising energy treatment of fresh fruit is the disinfestation of fruit for export. In Australia, Queensland fruit fly (Dacus tryoni) occurs in eastern Queensland and New South Wales and its presence restricts, through quarantine, the marketing of fresh fruit in other states and overseas. Many countries face similar plant quarantine problems in the export of horticultural produce, be it oranges from Australia, mangoes from the Philippines or orchids from Thailand. In the disinfestation treatment of fresh fruit the life-cycle of the insect must be broken to satisfy the quarantine requirements, but the fruit must not be damaged by the treatment, or reduced in quality for the consumer. In this discussion of disinfestation I will use the Queensland fruit fly as an example, since the story is typical of many such insect pests.

For many years many different fruits have been fumigated with EDB as a disinfestation treatment against several fruit flies, including Queensland fruit fly. However, the use of EDB to fumigate fruit is being phased out throughout the world, due to suspicions that it is carcinogenic and causes reproductive disorders. An alternative to this fumigation treatment is urgently required to maintain present exports, as well as for the development of new markets. Such an alternative should have widescale applicability to most, if not all, fruit types, be effective against a range of insect pests, and leave no harmful residues in the fruit. In addition the treatment must be economically and logistically feasible.

The longterm potential of any chemical alternative is doubtful, since health authorities may at any time introduce more stringent control of chemicals applied to food after harvest. Heat treatment, be it hot water or saturated hot air storage, has very limited applicability. Similarly cold sterilization is limited to the treatment of those temperate fruits which are not chilling sensitive.

Low dose irradiation treatment is effective against a range of insect pests in fresh fruit. A dose of 75 Gy will disinfest fruit against Queensland fruit fly; 200-250 Gy should be suitable for Medfly (*Ceratitis capitata*) and Oriental fruit fly (*Dacus dorsalis*); 150-200 Gy should disinfest fruit against Codling moth (*Cydia pomonella*). A 600 Gy irradiation treatment is the only feasible means of disinfesting mangoes against the mango seed weevil. Most fruits are relatively unaffected by this low dose irradiation treatment, and since no residue from the treatment remains in the fruit, the consumer's health is safeguarded. Provided that the irradiation treatment can be economically applied, it should be not only the most feasible alternative to chemical fumigation, but a viable quarantine treatment in its own right.

CONCLUSION

In this discussion of ionising energy treatment of fresh fruit one should remember that some alternatives to this treatment do exist. For example, the shelf life of some fruits can be extended by refrigeration. However, many fruit types are susceptible to chilling injury, and thus cannot be stored at low temperatures. Pathogens can often be controlled by postharvest chemical treatments, but many of these are restricted by public health regulations in many countries. As mentioned above, ethylene dibromide fumigation of fresh fruit is a typical example of the use of a postharvest chemical which has only recently been found to cause cancer and reproductive disorders in mammals.

Although ionising energy treatment may not solve all the problems associated with storage, transport and marketing of fresh fruit, it must be considered as a valuable tool to be used either alone, or in combination with other acceptable treatments, to provide fresh produce for the consumer.

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LECTURE 8

THE EFFECT OF IONISING IRRADIATION ON THE POSTHARVEST QUALITY OF VEGETABLES

S. MORRIS

THE EFFECT OF IONIZING IRRADIATION ON THE POSTHARVEST QUALITY OF VEGETABLES

Stephen C. Morris
Research Scientist, Gosford Horticultural Postharvest
Laboratory, Gosford, NSW.

The ultimate aim of all postharvest research and marketing is to minimize quality deterioration and present the fruits and vegetables to the consumer in as close to a freshly picked condition as possible. Postharvest deterioration of fruits and vegetables is associated with three factors.

1. Physiological - internal changes associated with ripening and senescence.
2. Pathological - attacks by pathogens, fungi, bacteria and insects.
3. Physical - mainly mechanical injury and dehydration.

Currently used methods to minimize these changes can be summarized as:

1. To minimize physiological deterioration - refrigeration (almost all fruits and vegetables), control atmospheres (apples, stone fruit, bananas), growth regulators (sprouting and delay ripening), irradiation (prevent sprouting on potatoes, onions).
2. To minimize pathological deterioration - refrigeration (almost all fruits and vegetables), fungicides and sterilants (many fruits and vegetables), heat treatments (cantaloupes, citrus), growth regulators (eg: 2,4-D against Alternaria on citrus), irradiation (strawberries), fumigants (eg: EDB against fruit fly).
3. Minimize physical deterioration - refrigeration (to reduce water loss), use of

cartons, punnets, trays, palletization etc. (to reduce water loss and physical damage), waxing (to reduce water loss).

The potential benefits of irradiation apply only to reducing physiological and pathological deterioration. Research to date has indicated irradiation does not reduce physical deterioration. In fact in most instances physical deterioration is actually increased by irradiation (Maxie and Abdel-Kader 1966). The overall benefit of an irradiation treatment is determined by balancing the benefits of any reductions in physiological and pathological deterioration against any increase in physical deterioration.

It should be noted from the number of treatments listed that irradiation does not produce results that are unattainable by any other treatment, irradiation therefore is in direct competition to other currently used treatments. Its widespread adoption as a postharvest treatment must depend on superior performances with regard to product quality, economics, safety both during application and of the final product, and finally consumer acceptance.

DEFINITION OF TERMS

A variety of terms are used to describe the effects of irradiation, some of which are encountered elsewhere and some of which are unique. These terms I feel need defining before I proceed in order to clarify the concepts are involved. The terms in alphabetical order are:

Decontamination: (Doses up to 1 mRad). The term is generally used in connection with spices (see radicidation).

Disinfestation: (see Insect Disinfestation).

Delayed Ripening: (up to 100 kRad). Ripening is delayed because the climateric of climateric fruit is retarded, along with subsequent senescence.

Insect Disinfestation: (up to 100 kRad). The treatment of produce to kill insect larvae or prevent emergence of adult insects.

Growth Inhibition: (up to 250 kRad). Describes the retarded growth that occurs in irradiated mushrooms and asparagus.

Radappertization: (greater than 2 mRad). Exposure to irradiation in sealed packaging to kill all food spoilage or disease organisms.

Radicidation: (Doses generally 300-1000 kRad). Exposure to irradiation at doses necessary to kill non-sporeforming pathogens.

Radiopasteurization: A term used to describe the effect of pathogen reduction by irradiation, it includes both radicidation and radurization.

Radurization: (generally 50-300 kRad). Exposure of food to irradiation at doses which reduce pathogen levels sufficiently to delay onset of spoilage.

Sprout Inhibition: (up to 15 kRad). Describes the control or inhibition of sprouting which occurs after exposure to low doses or irradiation.

REQUIREMENTS FOR IRRADIATION TO BECOME A PRACTICAL PROCESS

Having outlined the basic causes of postharvest deterioration and the currently used methods to minimize this deterioration, I would like to summarize the points which must be demonstrated for irradiation to be adopted as a practical process with any fruit or vegetable. These points are based on those first outlined over twenty years ago by Maxie and Sommer (1964) and frequently quoted since.

Food Safety

1. There must be no radiation-induced substances harmful to humans.

Appearance and Quality

2. There must be no major loss in nutritional quality of the produce.

3. Radiation-induced flavours and odors must not be objectionable.

4. Appearance of the produce must be attractive and typical of the species or variety.

Phytotoxicity

5. Post-irradiation susceptibility of the produce to infection by decay organisms must not be enhanced.

6. Radiation-induced changes in texture must not make the commodity excessively susceptible to impact or vibration injuries during transport.

Economics

7. Irradiation treatment must not entail extensive additional handling of the commodity.

8. The refrigeration requirement for the irradiated commodity must not be excessive.

9. The cost of the proçess must not exceed the benefits to be gained.

Safety.

All research work to date with irradiated produce has not found any harmful radiation-induced products (Maxie & Sommer 1964, Moy 1983). Therefore this first criteria has been adequately demonstrated for all fruits and vegetables.

Appearance and Quality

There has been shown to be reductions in levels of vitamins sensitive to radiation induced oxidixation such as Vitamin C at doses of less than or equal to 120 kRad. Because these losses are minor (generally below 15%) and no major losses of other nutritional compounds occur (Beyer et al. 1979, Moy 1983, Matsuyama & Umeda 1983, Maxine & Abdel-Dader 1966) therefore one can say that this criteria has also been met.

Demonstration of the remaining seven criteria, however depends on the particular horticultural produce and the type of detrioration that irradiation is being used to minimize. Therefore we must examine the efficiency of irradiation as a treatment for each vegetable.

Need for objective assessment of results and benefits.

Before I examine the experimental results obtained for each crop, I feel it is important to state the need for objectivity and for reasoned analysis of results obtained. A quote fom Maxie and Abdel-Kader (1966) should be carefully considered:

> "There is, perhaps, no area in applied biology where claims for the effectiveness of a protective process have been as extravagant as for the irradiation of fruits. Stories in the popular press have implied that irradiated fresh fruits may be kept for as long as two years with no loss in quality. This is a biological absurdity, for it ignores the living nature of the products and the endogenous degradative processes in them".

While most research workers in this field do objectively analysis and present data that includes any observed phytoxic effects, there is a significant minority of workers whose results are presented in a very partial and unscientific manner.

One striking example of this is in a paper by Cooper and Salunkhe (1963). In several tables they reported that strawberries irradiated with 300 kRad resulted in 100% marketable fruit (the controls had 0% marketable fruit). However, further comments in the text invalidate these results because strawberries irradiated with 300 kRad "developed a soft, spongy texture and had a water-soaked appearance" - strawberries with these characteristics can hardly be described as "marketable" fruit.

RESULTS FOR INDIVIDUAL VEGETABLES

There has not been nearly as much research on the effects of irradiation on vegetables as there has been on fruits. This is largely due to fruit being more valuable on a per unit weight basis. However, it should be noted that the only commercial irradiators ever used have been dedicated almost solely for irradiation of vegetables, specifically preventing sprouting of potatoes and onions. The two commercially operated plants are the currently functioning plant in Shiroho, Japan and the food irradiation plant in Canada that is now unfortunately no longer operating.

I would like in the following tables to consider virtually all published papers relating to the effects of irradiation on vegetables. Unfortunately, for the sake of brevity when the much more copious literature relating to spout inhibition of potatoes and onions was considered only some of the references relating to each effect was included .

Table 1. The effects of irradiation on "above ground" vegetables

Response	Dose kRad	Reference
TOMATOES		
Physiological Effects		
Delayed ripening of green and pink tomatoes and shelf life extension.	186	Salunkhe *et al.* (1959)
Reduce respiration and ripening when combined with IAA.	75	Mathur (1968)
Delayed ripening of 2-4 days at breaker.	500	Abdel-Kader *et al.* (1968b)
Pathological Effects		
Reduction of some storage rots	300	Bramlage & Lipton (1965)
Reduce decay, extend storage life (4-12d)	250	Abdel-Kader *et al.* (1968)
Phytotoxicity		
Softening of fruit and mottled colouring	200-300	Bramlage & Lipton (1965)
Mature, green and breakers very sensitive to irradiation, all tomatoes softening and slight off flavour.	250	Abdel-Kader *et al.*(1968b)
Uneven colouring and softening	186	Salunkhe *et al.* (1959)
Abnormal colour development and failed to ripen.	300-500	Abdel-Kader *et al.* (1968a)
Abnormal ethylene and pigment production.	200-400	Lee *et al.* (1968,1971).
Reduced ascorbic acid in ripening fruit.	200	Abdel-Kader *et al.* (1968c)
BELL PEPPERS (CAPSICUMS)		
Softening, yellowing and calyx discoloration	100-300	Bramlage & Lipton (1965)
Substantial inhibition of decay by severe phytotoxicity.	100-300	Farkas *et al.* (1966)
CUCUMBERS AND SQUASH		
Cucumbers and squash : no consistent decay control, softening and loss of colour	100-300	Bramlage & Lipton (1965)
Cucumbers : softening and loss of colour.	50	Morris *et al.* (1964)
CANTALOUPES AND HONEY DEW MELONS		
Cantaloupes : no consistent decay control softening of fruit	100-300	Bramlage & Lipton (1965)
Cantaloupes and honeydew melons : no consistent decay control, softening of fruit, off aromas and atypical flavours	300-400	Ravetto *et al.* (1967)

Table 2a. The effects of irradiation on "below ground" vegetables -

ONIONS

Response	Dose kRad	Reference
Sprouting:		
Control of sprouting, providing irradiated within 1-2 months of harvest	up to 15	Fu *et al.* (1979) Burton and Hannan (1957) Takano *et al.* (1974) Temkin-Garodetskii *et al.* (1972)
Pathogenicity:		
No effect on decay	up to 15	Dallyn & Sawyer (1959) Takano *et al.* (1974a) Umeda *et al.* (1970) Fu *et al.* (1979)
Reduce decay levels	best at 7	Nuttal *et al.* (1961)
Reduced decay at room temperature when used with fungicides	5	Wu *et al.* (1979)
Phytoxicity:		
Centre of bulbs (sprouts) become dark brown and die	5-15	Nair *et al.* (1973) Dallyn & Sawyer (1959) Nuttel *et al.* (1961) Tenkin-Garodetskii *et al.* (1972) Umeda *et al.* (1970)
Often accompanied by internal decay	5-15	Nuttal *et al.* (1961) Nair *et al.* (1973)
Maximum of 1 month life after removal from refrigeration	5-15	Takano *et al.* (1974)
Refrigeration required to minimize sprout browning	5-15	Atomic Energy of Canada Ltd. (1962)
Irradiated onions unsuitable for processing	5-15	Atomic Energy of Canada Ltd. (1962)

It is very important with onions that bulbs are irradiated within one month of harvest. For maximum quality bulbs should be cured before irradiation, also refrigeration is necessary to minimize internal browning and rotting (Sawyer and Dallyn 1961).

Table 2b. The effects of irradiation on "below ground" vegetables -

POTATOES

Response	Dose kRad	Reference
Physiology		
Sprouting prevented	5-15	Matsuzama & Omeda (1983) Burton & Hannan (1957) McQueen (1965) US Arm. Natick Lab. (1963) Fu *et al.* (1979)
Must be treated during the 1-6 month dormancy period		Hendel & Burr (1961)
Best if refrigerated after irradiation		Schwimmer *et al.* (1969) Umeda *et al.* (1969) Nair *et al.* (1972)
Considerable variation between cultivars	5-15	Sawyer and Dallyn (1961)
Pathology		
No significant reduction in decay due to irradiation and chemicals	10	Wu *et al.* (1979)
No significant increase in rots	5-15	Fu *et al.* (1979) US Army Natick Lab. (1963) Takano *et al.* (1977)
Significant increase in rots	10-30	Duncan *et al.* (1959) Meltilskii *et al.* (1967) Ghaneku *et al.* (1983)
Need for wound healing before irradiation to reduce rots		Metlitskii *et al.* (1967)
Phytotoxicity		
No significant effect on reducing sugars	5-15	Cloutier *et al.* (1959) Otaga (1973)
Increased concentration of reducing sugars and sweetening (reconditioning after storage can decrease levels)	5-15	Rubin & Metlitskii (1958) Burton *et al.* (1959) Grunewald (1973) Sparenberg (1977) Takano *et al.* (1972) Moore *et al.* (1963) Asselbergs & Wethington (1960) Takeno *et al.* (1974)

Table 2b. Continued (POTATOES)

Response	Dose kRad	Reference
Phytotoxicity (continued)		
Death and localized rotting of emerged buds	5-15	Umeda et al. (1969)
Browning of raw, but especially cooked potatoes (reduced if irradiated 3 months after harvest)	5-15	Ogata et al. (1970a,b) Pendharker & Nair (1975) Nair et al. (1972) Ogata et al. (1970b) Tatsumi et al. (1972)
Decreases wound healing ability (with very different physical structure: decreased phenolics 40%, free lipids ~50%, phytoalexins ~50%, suberin ~25%)	10	Ghanekar et al.(1983)
	25	"
		Matsuyama & Umeda (1983)
Matsuyama & Umeda (1983), p.176.		
"The maximum dose for sprout control of tubers and onions is 15 kRad, preferably 10 to 12 kRad. With potato tubers, over 15 to 20 kRad increases storage rot, spoilage, sweetening, decreases vitamin content and brings about changes in chemical composition which did not disappear during subsequent storage".		
Greening		
Chlorophyll synthesis inhibited by irradiation	100-250	Schwimmer et al. (1957)
(however the inhibition of Chl synthesis due to irradiation declines with time. There is no effect on light induced synthesis of the toxic glycoalkaloids associated with greening: synthesis of wound induced glycoalkaloids is inhibited.		Schwimmer & Weston (1958)
Potato Tuber Moth		
Prevents emergence of adults	20	Nair et al. (1972)

Table 2c. The effect of irradiation on "below ground" vegetables -
CARROTS, GARLIC, GINGER, YAMS; and on MUSHROOMS

Response	Dose kRad	Reference
Prevent sprouting of roots and crown	10-20	Mikaelsen *et al.* (1956) Madsen *et al.* (1959)
	12	McQueen (1963)
Increase shelf life by a few days at room temperature	75	Ismail & Afifi (1976)
Significant softening	≥ 10	"
Inferior flavour	100	"
GARLIC		
Effective control of sprouting	10-25	Curzio & Ceci (1984) Fu *et al.* (1979)
No significant effect on rots	25	"
No effect of irradiation on garlic volatiles	25	Curzio & Ceci (1984)
GINGER		
Inhibited sprouting	8	Fu *et al.* (1979)
Controlled decay No significant organoleptic effect	15	Gonzales *et al.* (1969)
No effect rotting	25	Fu *et al.* (1979)
YAMS		
Inhibited sprouting	7.5-15	Pablo *et al.* (1975)
Internal tissue damage	> 15	"
MUSHROOMS		
Delay of cap opening and senescence	100 200	Anon (1970) Maxie *et al.* (1971)
ASPARAGUS		
Inhibition of growth	15	Maxie *et al.* (1971)

OVERALL BENEFITS OF IRRADIATION

I would like to present several tables summarizing research results by leading reviewers in this field and add my own conclusions based on extra papers. The first table is produced by Akamine & Moy (1983)

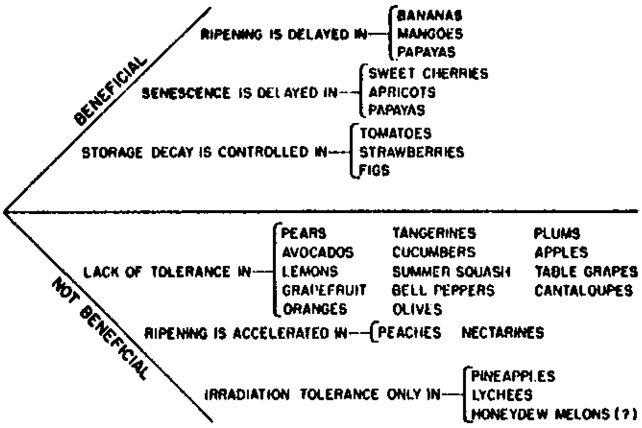

FIGURE 1. The response of 27 fruits to irradiation.

This table summarizes results of research work for 27 fruits and vegetables. They divided into two major catagories, namely where irradiation was beneficial and where it was not. It can be clearly seen that for the majority of fruits and vegetables irradiation is not beneficial. For 8 out of the 27 however, the effect is classified as beneficial; of these only one is a vegetable (statistically rather than botanically speaking) namely tomato. However, the inclusion of tomato in the beneficial list is puzzling because in the previous chapter to this Moy (1983) (who is one of the authors of this table) concludes that levels of 200-300 kRad are required to control decay in tomatoes and he states that these levels produce "some reduction of storage decay but mottling and softening occur".

A further problem with tomatoes is that only fruit at the pink or red colour stages has any tolerance to irradiation, since mature green and breaker fruit are very sensitive to injury by irradiation (Abdel-Kader <u>et al</u> 1968a, Salunkhe <u>et al</u> 1959). Delayed ripening of tomatoes by irradiation, while possible (Salunkhe et al 1959), is not feasible due to abnormal ripening of fruit. A combination treatment of irradiation and IAA was reported by Mathur (1968) and IAA to delay ripening at 75k rad. This is much lower than the previously reported levels of 200 kRad (Salunkhe et al 1959; Abdel-Kader et al 1968b). Therefore a combined irradiation and growth hormone treatment may have potential for tomatoes, but further investigation is required.

The other vegetables (statistically speaking) in the figure of Akamine & Moy (1983), are cucumbers, summer squash, bell peppers, cantalopes and honeydew melons. The effect of irradiation on these vegetables is not beneficial; this is basically due to the phytoxic or harmful effects on the vegetable itself.

Another vegetable not mentioned in this list are carrots. According to Ismail & Afifi (1976), irradiation can increase storage life by a few days at room temperature, although it does not result in a significant increase in storage life when carrots are refrigerated. Flavour is not significantly effected by the 75 kRad required, although the texture of irradiated carrots is softer and less crisp.

In summary then it would seem that for vegetables the use of irradiation to delay ripening or to reduce decay is not a beneficial process. These are not solely my conclusions but also those of all major recent reviewers (Akamine & Moy 1983, Moy 1983, Maxie et al 1971). To quote from Moy (1983), p.101:

> "A major problem in applying ionizing radiation at the radurization dose level (mostly 200-300k rad, sometimes as high as 500-600k rad) to fruits and vegetables is that the host is often more sensitive to quality change such as softening that the pathogens for which the treatment is intended".

and again

> "Therefore, results of various studies have indicated that it is not practical to prescribe a single radiation dose as being adequate to control a given decay-causing organism in a specific host. The most promising application is to combine ionizing radiation with heat treatment so as to take advantage of the synergistic effect between the two in order to use a lower dose and lesser amount of heat to achieve the purpose of pasteurization".

It is obvious from this quote that irradiation to control decay (and in Moy's case he is including fruits and vegetables) is not an effective treatment unless used as part of a double treatment with heat suggested as being the best additional treatment. Also the use of correct temperature management, or refrigeration, is usually necessary maximize the potential extra shelf life (Akamine & Moy 1983, Moy 1983, Pablo _et al_. 1975, Maxie _et al_. 1971). This being the case, a significant benefit of irradiation is only possible when a separate heat treatment (best applied after irradiation, Buckley _et al_. 1969) and refrigeration are both included as part of the overall package.

The next summary table I would like to consider is that from Maxie _et al_. (1971). These tables summarize fifteen years of the most extensive work ever carried out on irradiation of fruits and vegetables. Of the many products included, five are vegetable (or non-fruits), namely tomatoes, asparagus, mushrooms, potatoes and cantaloupes.

The overall effects of irradiation on tomatoes are concluded to be harmful (agreeing with Moy 1983 but disagreeing with Akamine & Moy 1983), as are the effects of irradiation on cantaloupes. Beneficial effects at non-phytoxic doses are noted for growth inhibition of asparagus and mushrooms. Finally the beneficial effects for sprout control of potatoes are mentioned.

Table 1. **Comparison of maximum tolerable doses and minimum dose required for desired technical effects on selected fresh fruit and vege**

Commodity	Desired technical effect	Estimated max tolerable dose in Krad	Estimated min dose required in Krad	Phenomena limitin commercial applic
Apples	Control of scald and brown core	100 - 150	No-effect below 150	Cheaper, more eff alternatives, tissue softening
Apricots	Inhibition of brown rot	50	200	Tissue softening
Asparagus	Inhibition of growth	15	5 - 10	Economics, short season, small acrea
Avocados	Inhibition of ripening and rot	25 25	None applicable	Cheaper, more eff alternatives, brow and softening of t
Bananas	Inhibition of ripening	50	30-35	Cheaper, more eff alternatives
Boysenberries	Inhibition of gray mold	100	200	Tissue softening
Cantaloupes	Inhibition of ripening	200	No effect below 200	Cheaper, more eff alternatives
Lemons	Inhibition of penicillium rots	25	150-200	Severe injury to fr doses of 50 Krad o more, cheaper, mo effective alternativ
Limes	Inhibition of penicillium rots	25	150-200	Pronounced off-fla cheaper, more effe alternatives
Mushrooms	Inhibition of stem growth and cap opening	100	200	Cheaper, more effe alternatives
Nectarines	Inhibition of brown rot	100	200	Tissue softening
Oranges	Inhibition of penicillium rots	200	200	Cheaper, more effe alternatives, no tec cal effect under commercial conditi
Papayas	Disinfestation of Hawaiian fruit fly	75-100	25	Economics, inadeq acerage
Peaches	Inhibition of brown rot	100	200	Tissue softening
Pears	Inhibition of ripening	100	250	Abnormal ripening cheaper, more effec alternatives
Potatoes	Inhibition of sprouting	20	8-15	Cheaper, more effe alternatives
Raspberries	Inhibition of gray mold	100	200	Tissue softening
Strawberries	Inhibition of gray mold	200	200	Cheaper, equally effective alternative
Table grapes	Inhibition of gray mold	25-50	1,000	Tissue softening, severe off-flavors, cheaper, more effec alternatives
Tomatoes	Inhibition of alternaria rot	100-150	300+	Abnormal ripening, tissue softening

This leads us to what is probably the best potential use of irradiation for vegetables, namely sprout control. The relative potential of this treatment is seen by the fact that the only commercial use of a food irradiator in the world is used for sprout inhibition of potatoes in Japan. Also for the total of twenty nine specific fruit and vegetable irradiation treatments uses registered with unlimited clearances; twenty three of these treatments (80%) are for sprout inhibition of potatoes, onions and garlic (Goresline 1983).

Growth inhibition due to irradiation has been observed for both mushrooms and asparagus. The major benifit for mushrooms is a delay on cap opening and hence an extension of shelf life (Anon 1970, Masine et al 1971), however it is questionable wether the benit of irradiation are significanly greater than that due to refigeration alone.' For asparagus irradiation has benificial affects preventing growth and reducing bending (Marie et al 1971), however again ;it is questionable wether the effects of irradiation are significantly better than effects of refrigeration.

In an excellent review, Matsuyama and Umeda (1983) thoroughly cover all the literature on sprout inhibition (mainly for potatoes and onions). Prompt treatment with irradiation after an adequate curing treatment is particularly important. Treatment must be be within 1 month for onions and within the 1-3 month dormancy period for potatoes. Correct temperature control of storage conditions is essential in order to minimize the development of after-cooking browning in potatoes and centre browning and decay in onions which can be a problem when irradiated. It is important to note that irradiation has significant benefits for sprouting control of potatoes and onions only as part of a combined programme of treatments (Matsuyama & Umeda 1983). This programme should include curing after harvest and correct temperature management during storage. It is important to note that irradiated onions are unsuitable for processing; this is due to browning and death of the centre shoot (Atomic Energy of Canada 1962).'

The greening of potatoes due to exposure to light is a significant problem for the potato industry. However, the benefit of irradiation on potato greening are not significant for several reasons. Greening involves synthesis of harmless chlorophylls and unfortunately the potentially toxic glycoalkaloids. Only the synthesis of chlorophyll is inhibited by irradiation and this inhibiting effect rapidly diminishes during subsequent storage of the tubers. The synthesis of glycoalkaloids (including solanine which occurs during greening) are not inhibited at all. Irradiation does however, inhibit the synthesis of glycoalkaloids which are produced as a result of wounding (Wu & Salunke 1977b). A further problem is that the doses required (200 kRad) are very much greater than the phytotoxic limit of 20 kRad reported by Matsuyama and Umeda (1983).

Other vegetables for which irradiation can be beneficially used to control sprouting are garlic, sweet potatoes, ginger and yams.

A potentially beneficial use for irradiation of potatoes is to disinfest potatoes which contain potato tuber moth. For this purpose a dose of 20 kRad is required (Sawyer & Dallyn 1961). Insect disinfestation of potatoes would seem to be a beneficial use of irradiation.

Economic Viability

From our examination of the literature the only beneficial effects of irradiation are those that which use low does of 20 kRad or less which cause minimal phytotoxic effects. These low doses are capable of preventing physiological deterioration due to growth and sprouting and of preventing pathological deterioration due to insects. The two specific physiological deterioration processes that are significantly effected by irradiation are - growth inhibition of asparagus and mushrooms, and sprout inhibition of potatoes, onions and garlic. Both these processes only require low doses of less than 15 kRad. Pathological deterioration of potatoes due to attack by potato tuber moth is controlled by irradiation at slightly higher doses of 15 kRad.

If we recall our nine criteria for irradiation to become a practical process, these five crops of asparagus, garlic, mushrooms, onions and potatoes can be said to satisfy the first six points covering food safety, appearance and quality, and phytotoxicity. However, the remaining three economic criteria must also be demonstrated.

Several reviews have principally dealt with the logistics and economic feasibility of irradiation as a treatment for fruits and vegetables (Maxie et al. 1971, Beattie & Wiblin 1984 and Sommer & Mitchell 1985). All these reviews point out the necessity for irradiation facilities to be located at the production centres of the horticultural crop or crops that are to be treated. Unless this is so, much of the benefits of irradiation treatment will be lost due to very high additional transport costs and also excessive delays before treatment and during marketing. In order for the location of irradiators in production areas to be economically viable, the crop much be of high value per unit of weight and there must also be a high density of producers preferably located close to a large town or city. I would now like to examine the economic feasibility of treatment of these five vegetables with reference to Australia. However, the same principles relating to economic viability would need to be applied to each crop under consideration in other countries. Due to different values of crop, density of producers, requirements for storage durations, etc. The conclusions regarding economic feasibility may not necesarily be the same as those which apply to Australia.

The asparagus and potato industries in Australia are both spread over many production districts and therefore do not have a high enough density of growers to warrant building an irradiator in any one of the producing districts. The production of mushrooms however is localised with a majority of growers located in the Windsor district near Sydney. Production of onions and garlic also are fairly centralized with a concentration of onion and garlic growers in NSW in the MIA irrigation district. Other major onion centres are the Launceston region in Tasmania and the Riverlands district in South Australia.

Given that mushrooms, onions and garlic have production districts with a high grower density, the relative economic benefits of irradiation compared to alternative physiological deterioration prevention strategies must also be established. For mushrooms the marketing chain in Australia is usually rapid enough that generally no shelf life extension is necessary. Where a longer shelf life is necessary refrigeration is usually used to increase this by several days. Because only a small proportion of mushrooms currently are refrigerated to extend shelf life it would seem unlikely that there would be sufficient demand for an irradiation treatment to make this viable economically.

The sprouting in onions and garlic during storage is not currently regarded as a major problem in Australia (Beattie & Wiblin 1983). This is due to the virtual year round supply of onions produced in the different climatic conditions in Australia. Currently there is virtually no sprout inhibition treatments applied to onions and garlic in Australia, either using chemical inhibitors, i.e. maleic hydrozide or using refrigeration at low temperatures to inhibit sprouting. Since virtually no sprout inhibition treatments are currently applied, there would not seem to be sufficient demand for irradiation to make it a viable economic treatment for sprout inhibition of onions or garlic.

In summary then, virtually all irradiated fruits and vegetables satisfy the first two criteria of being safe for human consumption and there being no major reduction in nutritional quality. The majority of vegetables fail to satisfy criteria numbers 3 to 6 covering appearance, quality and phytotoxicity because they are more sensitive to irradiation than the pathogen involved. It would seem that only irradiation treatments with low irradiation doses of 20 kRad or less are sufficiently non-phytotoxic to allow the treatment to have an overall benefit. These treatments include growth inhibition, sprout inhibition and insect disinfestation. However, the sensitivity of each individual crop to the low levels of irradiation must be tested and phytoxicity may vary considerably between crops. Of the five vegetable crops that have significant physiological or pathological benefits due to irradiation in Australia only mushrooms, onions and garlic have the required centralized production areas. However, irradiation as a treatment for these three products fail to satisfy the last two economic criteria because there is insufficient demand and ecomomic advantage of irradiation compared to existing industry practice.

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LECTURE 9

BASIC RADIATION CHEMISTRY FOR THE IONISING ENERGY TREATMENT OF FOOD

P. MOORE

BASIC RADIATION CHEMISTRY FOR THE IONISING ENERGY TREATMENT OF FOOD

P. W. MOORE (AAEC)

Before we can understand the chemistry involved in the irradiation of complex substances such as food we need to have some appreciation of the reactions involved and the products formed when ionising energy interacts with simple substances such as water and dilute solutions. In extrapolating the effects from the simple to the complex we will notice some constant features and some differences.

The first thing that must be said is that under the conditions used for treatment of foods, ionising energy interacts only with the outer electrons of atoms, not with the nucleus. Consequently no radioactivity whatsoever is induced in the material being irradiated. We are concerned with chemical changes in the food, not nuclear changes.

A question that needs to be answered is whether the chemical changes are similar to changes produced by other methods of food treatment. If unusual compounds are produced, or known compounds in unusually high amounts, special care is needed to ensure that these have no undesirable consequences.

The Earliest Processes

In practice only gamma radiation (from ^{60}Co or ^{137}Cs) or electrons (from electron accelerators of different types) are used for food irradiation. When a gamma ray passes through material it produces ionisation (reaction 1) if sufficient energy is imparted to knock an orbital electron out of the atom, and excitation (reaction 2) if the electrons are merely promoted to higher energy levels in the atom.

$$M \rightsquigarrow M^{\cdot +} + e^- \qquad (1)$$

$$M \rightsquigarrow M^* \qquad (2)$$

The electrons produced in reaction 1 have sufficient energy to react with other atoms producing further ionisation and excitation. These high speed electrons act in the same way as electrons produced by an electron accelerator, hence the early reactions are essentially the same for electron irradiation as for gammas.

The Macroscopic Picture

Cobalt-60 produces gamma rays of two energies (1.33 and 1.17 MeV) and these lose about half their energy in 12cm of unit density material such as water. On the other hand, electrons of similar energies penetrate only about 5mm in unit density material. Consequently ionisation and excitation produced by gamma irradiation can occur throughout a material under treatment but that produced by electron beam irradiation is produced only in about the first centimetre.

The Microscopic Picture

It is important also to have some understanding of the microscopic picture. A 1 MeV electron, irrespective of its method of production, produces as many as 10^5 ionised species. On the microscopic scale these species are not uniformly produced throughout the irradiated zone, but occur in clusters along the main track of the electron or along branch tracks produced by secondary and tertiary electrons. As the electron progressively looses energy (i.e. slows down) the clusters are formed closer together and begin to overlap forming dense regions of ionisation surrounded by an envelope of excitation. Because of the high concentration many of the species formed in these dense regions react with each other before they can escape into the bulk medium where reaction with solutes is possible. The tendency towards recombination is greater in materials of low dielectric constant such as organic liquids. In polar media with high dielectric constants the attractive forces between the positive and negative ions are weaker, and many more of the electrons escape and become solvated.

Primary Species in Water and Aqueous Solutions

Since most foods contain from about 40 to 95 percent water the radiation chemistry of foods is, to a large extent, that of water. We can therefore rewrite equations 1 and 2 as follows:

$$H_2O \rightsquigarrow H_2O^{\cdot +} + e^- \qquad (3)$$

$$H_2O \rightsquigarrow H_2O^* \qquad (4)$$

After about 10^{-11} seconds these reactive species have undergone various reactions to give the following species:

	$e^-_{(aq)}$,	H_3O^+,	$H^\cdot$,	$^\cdot OH$,	H_2,	H_2O_2
G value	2.7	2.8	0.55	2.8	0.45	0.7

Although these are not the first species formed they are called "primary species" since they are the earliest species taking part in reactions outside the electron tracks (or spurs). The amounts of each species formed are expressed in terms of the G value which is defined as the number of molecules of product formed for each 100 eV of energy absorbed. The radical and charged species are extremely reactive and do not last long. They disappear by reactions between themselves or with solutes.

Direct and Indirect Reactions

In dilute solutions (<1M) nearly all the radiation is absorbed by the water; very little by direct action on the solute itself. Thus the relatively high yield of reactive species formed from the water may cause severe degradation of solutes present in low concentration. Quite often there is a concentration effect, as shown in Figure 1, where the extent of degradation increases with decreasing concentration.

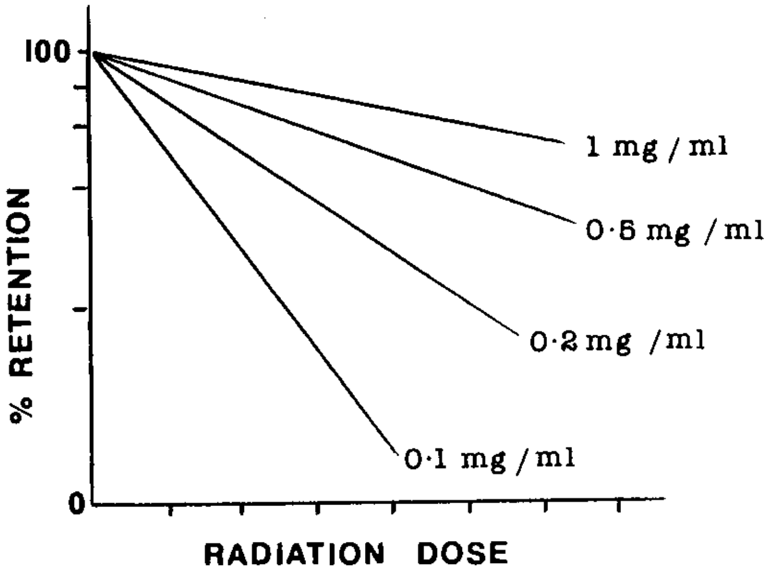


Fig. 1

This type of effect is evidence of indirect action, usually via the solvent, and is in contrast to direct action where the extent of reaction is proportional to the radiation dose but independent of the concentration when expressed in this way. Moreover, because direct effects become increasingly important at higher concentrations, not only is the extent of change affected, but the products themselves may change also.

Reactions of Primary Species

The primary products of water hydrolysis are both oxidising and reducing. At one extreme, hydroxyl radicals ($^{\bullet}OH$) are strongly oxidising, and at the other, the hydrated electron ($e^-(aq)$) is a very strong reductant. In acid solution $e^-(aq)$ is converted to a hydrogen atom (reaction 5).

$$e^-_{(aq)} + H_3O^+ \longrightarrow H^{\bullet} + H_2O \qquad (5)$$

which is a weaker reductant. Hence the balance between oxidation and reduction will depend on conditions of pH, the presence of electrophilic compounds which will react rapidly with the hydrated electron, the presence or absence of oxygen, and the redox potential of metal ions present.

If there are no suitable solutes with which to react the primary species are eventually removed by reactions between each other (reactions 6-8)

$$^{\bullet}OH + ^{\bullet}H \longrightarrow H_2O \qquad (6)$$

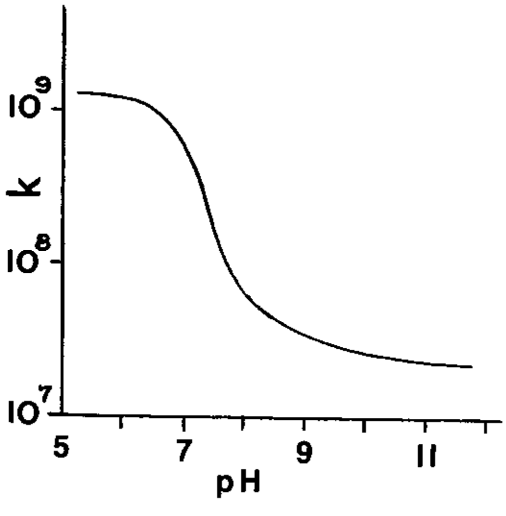
$$^{\bullet}OH + e^-_{(aq)} \longrightarrow OH^- \qquad (7)$$

$$^{\bullet}OH + ^{\bullet}OH \longrightarrow H_2O_2 \qquad (8)$$

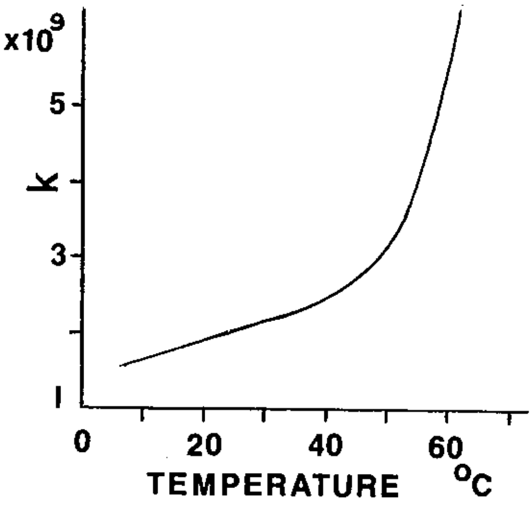
The extent of reactions between primary species is greater at higher concentrations of these species outside the spurs, i.e. at higher dose rates.

Reactions Involving Hydrated Electrons

1. Hydrated electrons react with peptide bonds (-CONH-) in proteins forming adducts that are readily oxidised. Reaction rates with proteins depend both on the chemical structure of the component amino acids and on the conformation and nature of the protein as a whole. The latter properties are affected by ionic strength, pH and temperature. Typical changes in rate constants for reactions involving $e_{(aq)}$ and proteins are shown in Figures (2) and (3).



(Fig.2)



(Fig.3)

2. Hydrated electrons react with sulfhydryl groups in foods such as meat (reaction 9)

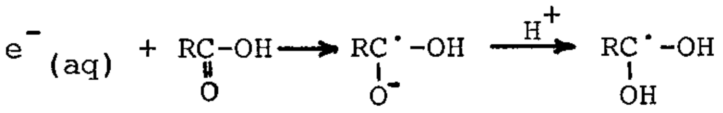
$$e^-_{(aq)} + RSH \xrightarrow{H^+} R^\bullet + H_2S \qquad (9)$$

with possible production of "rotten-egg" odour.

3. Hydrated electrons react with iron-containing heme proteins, the red pigments in meat. In the absence of oxygen, hydrated electrons cause changes in the meat pigment responsible for the colour of cooked meat, metmyoglobin, from an oxided grey brown colour to a reduced purplish red. The original colour is restored by exposure to air and light.

4. Hydrated electrons cause reduction of enzymes by attack on the protein part of the molecule or, if the enzyme is a protein complex of a reducible metal such as Mn, Cu or Fe, on the metal atom.

5. Hydrated electrons react with acids in fruit and vegetables (reaction 10)



$$e^-_{(aq)} + R\underset{\overset{\|}{O}}{C}-OH \longrightarrow R\underset{\overset{|}{O^-}}{C^\bullet}-OH \xrightarrow{H^+} R\underset{\overset{|}{OH}}{C^\bullet}-OH \qquad (10)$$

Similar reactions with esters and fatty acids occur only to a minor extent because the hydrated electron is produced in a different phase. However reactions could occur via non-solvated electrons in the lipid phase, and could occur to a significant extent in micellar systems (i.e. emulsions). The chemistry of micellar systems is governed to a large extent by the charge on the surface of the micelles. The hydrated electron is unreactive towards micelles carrying the same charge i.e. to negatively charged micelles stabilised by fatty acid anions such as oleates, linoleates and stearates. Reaction with positively charged or neutral micelles may also be slow because the electron has to cross a phase boundary. Generally speaking, reactions in micelles involve radicals produced in both the water and lipid phases.

6. Hydrated electrons may react with nitrates and nitrites present in vegetables and cured meats (reactions 11, 12)

$$e^-_{(aq)} + NO_3^- \xrightarrow{H^+} NO_2 + OH^- \qquad (11)$$

$$e^-_{(aq)} + NO_2^- \xrightarrow{H^+} NO + OH^- \qquad (12)$$

Subsequent reaction between nitrous oxide and amines in the food could lead to production of carcinogenic nitrosamines. Such reactions are also possible during cooking of non-irradiated foods (in the frying of bacon for example) hence it is not a simple matter to decide whether destruction of residual nitrite by irradiation is beneficial or not. Nitrites are added to foods such as bacon, ham, corned beef and frankfurts to inhibit bacterial growth (in particular, Clostridium botulinum) and to impart a characteristic colour and flavour. Because irradiation achieves the first objective it is sometimes possible to achieve the second using reduced levels of nitrite or by eliminating it entirely.

Reactions Involving Hydrogen Atoms

Below about pH4 hydrated electrons are converted to H atoms (reaction 13)

$$e^-_{(aq)} + H^+ \rightleftharpoons H^{\cdot} \qquad (13)$$

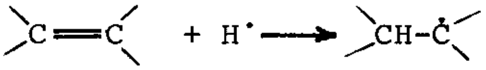
Between pH4 and 11 both $e^-_{(aq)}$ and $H^{\cdot}$ are present, although reactions of $e^-_{(aq)}$ predominate. Both are reducing species and undergo similar reactions, although they may at times give different volatile products.

1. Hydrogen atoms react with S-containing amino acids (reaction 14)

$$\begin{tikzcd} H^{\bullet} + RSH \arrow[r] \arrow[dr] & RS^{\bullet} + H_2 \\ & R^{\bullet} + H_2S \end{tikzcd} \qquad (14)$$

The radicals produced may then take part in further reactions.

2. Hydrogen atoms add to unsaturated compounds (reaction 15)



(15)

3. Hydrogen atoms may abstract hydrogen from saturated compounds (reaction 16)

$$RH + H^{\bullet} \longrightarrow {}^{\bullet}R + H_2 \qquad (16)$$

Reactions Involving Hydroxyl Radicals

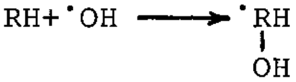
Hydroxyl radicals take part in electron transfer, displacement, hydrogen abstraction and addition reactions (reactions 17-20)

electron transfer $X^- + {}^{\bullet}OH \longrightarrow X^{\bullet} + OH^-$ (17)

displacement $RX + {}^{\bullet}OH \longrightarrow ROH + X^{\bullet}$ (18)

hydrogen abstraction $RH + {}^{\bullet}OH \longrightarrow R^{\bullet} + H_2O$ (19)

addition



$$RH + {}^{\bullet}OH \longrightarrow {}^{\bullet}\underset{\displaystyle OH}{\overset{}{RH}}$$

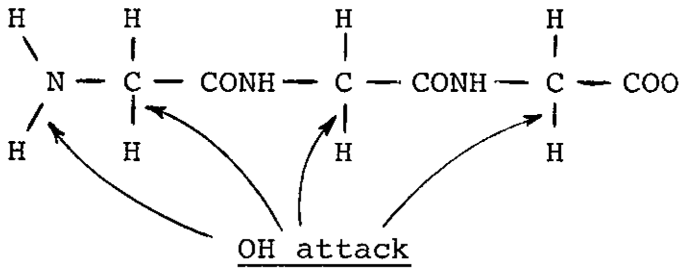
(20)

1. The chlorine radical ($Cl^{\bullet}$) is produced in saline medium by transfer of an electron from the chloride ion to the hydroxyl radical. This radical reacts with another chloride ion forming a dichloride anion radical (${}^{\bullet}Cl_2^-$) which is the oxidising species in saline solutions (reaction 21).

$$Cl^- + {}^{\bullet}OH \longrightarrow Cl^{\bullet} + OH^- \xrightarrow{Cl^-} {}^{\bullet}Cl_2^- \qquad (21)$$

2. Hydroxyl radicals rapidly abstract hydrogen from amino acids and proteins in the unprotonated form

i.e.



$H_2N-CH_2-CONH-CH_2-CONH-CH_2-COO$

In the presence of oxygen, hydroxy and hydroperoxy derivatives are eventually formed. The extent of reaction is much less with peptides in the protonated (i.e. zwitterion) form. As a result the pH dependence on the reaction rate constant for OH$^{\bullet}$ attack on aliphatic amino acids is generally as shown in Figure 4.

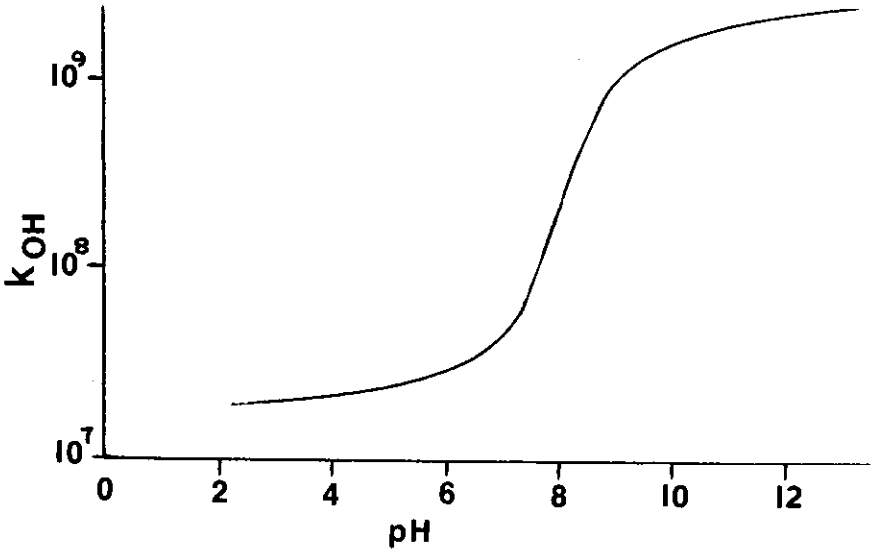


Fig.4

Reactions of this type play an important part in the protection provided by amino acids to radiation sensitive compounds such as enzymes and vitamins present in very low concentrations.

2. Hydroxyl radicals attack sulphydryl groups in sulphur-containing amino acids and enzymes (reaction 22), resulting in high sensitivity towards radiation damage.

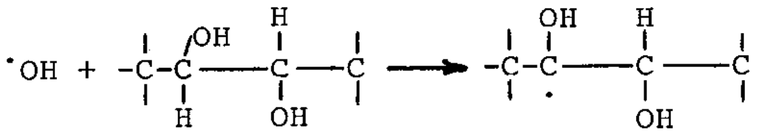
$$RSH + {}^{\bullet}OH \longrightarrow H_2O + RS^{\bullet} \qquad (22)$$

In the presence of oxygen various reactions leading to peroxy and hydroperoxy derivatives occur.

3. Hydroxyl radicals preferentially add to aromatic and heterocyclic rings on amino acids and peptides containing these residues. Hydrogen abstraction is secondary in these compounds.

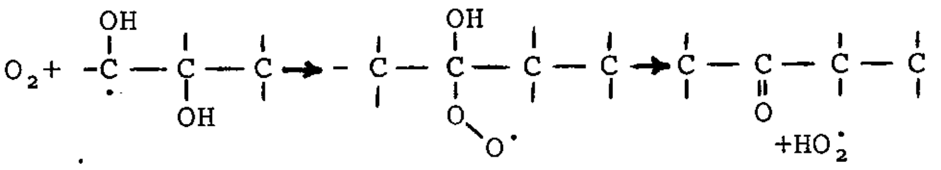
4. Hydrogen abstraction occurs by OH attack on acids and esters. The radicals formed may subsequently dimerise or disproportionate. An example of the latter reaction is the formation of pyruvic acid in irradiated meat by the disproportionation of radicals from lactic acid.

5. Hydrogen abstraction occurs by OH attack on carbohydrates (reaction 23)



$${}^{\bullet}OH + -\overset{|}{\underset{|}{C}}-\overset{OH}{\underset{H}{C}}-\overset{H}{\underset{OH}{C}}-\overset{|}{\underset{|}{C}} \longrightarrow -\overset{|}{\underset{|}{C}}-\overset{OH}{\underset{\bullet}{C}}-\overset{H}{\underset{OH}{C}}-\overset{|}{\underset{|}{C}} \qquad (23)$$

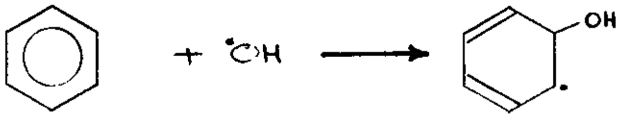
In oxygenated conditions peroxy and carbonyl compounds are formed (reaction 24)



$$O_2 + -\overset{OH}{\underset{\bullet}{C}}-\overset{|}{\underset{OH}{C}}-\overset{|}{\underset{|}{C}} \longrightarrow -\overset{|}{\underset{|}{C}}-\overset{OH}{\underset{O-O^{\bullet}}{C}}-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}} \longrightarrow \overset{|}{\underset{|}{C}}-\overset{}{\underset{O}{\overset{\|}{C}}}-\overset{|}{\underset{|}{C}}-\overset{|}{\underset{|}{C}} + HO_2^{\bullet} \qquad (24)$$

6. Addition reactions occur with unsaturated compounds especially conjugated polyenes. Thus addition followed by polymerisation may occur with unsaturated oils.

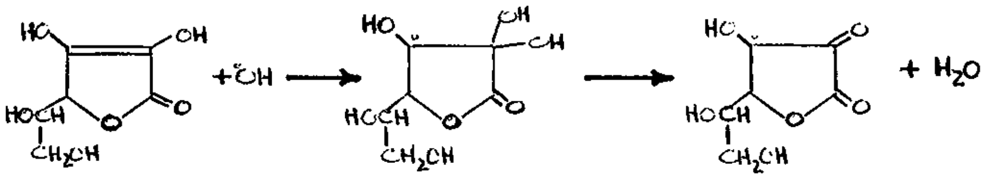
7. Hydroxyl radicals add to aromatic rings forming cyclohexadienyl radicals (reaction 25)



(25)

Even when the compound contains aliphatic side chains reaction is still predominantly with the aromatic ring.

8. The hydroxyl radical adds to ascorbic acid with subsequent elimination of water from the molecule (reaction 26)



(26)

The ascorbic acid radical reacts giving a variety of products which may condense with amino acids causing browning (Maillard reaction).

Oxygen

Oxygen is one of the commonest solutes since aqueous solutions in contact with air contain dissolved oxygen at a concentration of 2.6×10^{-4}M at ambient temperatures. Oxygen is a diradical and reacts readily with other free radicals produced by radiolysis. For example it readily adds to alkyl radicals to give peroxy radicals (reaction 27).

$$^{\bullet}RH + O_2 \longrightarrow RO^{\bullet}OH \qquad (27)$$

Another product of oxygen is the superoxide anion radical ($^{\bullet}O_2^-$) (reaction 28).

$$O_2 + e^-_{(aq)} \longrightarrow {}^{\bullet}O_2^- \qquad (28)$$

The reactions of this product are pH dependent because of the equilibrium

$$^{\bullet}O_2^- + H^+ \rightleftharpoons HO_2^{\bullet} \qquad (29)$$

At pH6 the equilibrium is such that about 7% is in the $HO_2^{\bullet}$ form, and at lower pH the amount is correspondingly greater. Both $^{\bullet}O_2^-$ and $HO_2^{\bullet}$ can undergo a variety of reactions frequently yielding molecular products such as hydrogen peroxide. Another possibility is reaction with peroxy radicals (reaction 30)

$$\dot{R}OOH + {}^{\bullet}O_2^- + H^+ \longrightarrow HROOH + O_2 \qquad (30)$$

The formation of hydroperoxy compounds produces rancid off-flavours. These can often be prevented or reduced by vacuum or gas packaging prior to irradiation.

In the absence of oxygen some radical species may recombine to produce compounds that are not noticeably different from the original material. However by reacting rapidly with these radicals oxygen may block these reactions. For example in the absence of oxygen the irradiation of many plastic materials causes changes in cross-linking and unsaturation which, except at high radiation doses, are insufficient to materially affect appearance and mechanical properties. However, in the presence of oxygen, main chain scission may take precedence over cross linking and carbonyl compounds may be formed leading to discoloration and changes in surface properties.

These examples are sufficient to show that oxygen will react with both primary and secondary radicals, and therefore becomes used up unless replaced by diffusion of oxygen into the system. This condition may be expected after a radiation dose of about 50 k rad (0.5 KGy).

Hydrogen Peroxide

It can be seen from the above discussion that hydrogen peroxide is formed in aqueous media both in the presence and absence of oxygen. The fate of the hydrogen peroxide varies according to the conditions. In pure water some is destroyed by reaction with reducing species (reactions 31-32)

$$e^-_{(aq)} + H_2O_2 \longrightarrow {}^{\bullet}OH + OH^- \qquad (31)$$

$$H^{\bullet} + H_2O_2 \longrightarrow {}^{\bullet}OH + H_2O \qquad (32)$$

particularly if escape of hydrogen gas is prevented. Under these conditions the hydrogen peroxide eventually attains a steady-state concentration where it is destroyed as fast as it is formed. If hydrogen is able to escape, reactions leading to the production of oxygen are favoured, the net effect being the conversion of water into hydrogen and oxygen. Similar reactions occur in the presence of trace organic impurities due to interference by these impurities in certain radical chain reactions. Alternatively, hydrogen peroxide may react with solutes causing either oxidation or reduction depending upon the redox potential of the solute ions (e.g. reactions 33-34).

$$2Fe^{2+} + H_2O_2 \longrightarrow 2Fe^{3+} + 2OH^- \qquad (33)$$

$$2Ce^{4+} + H_2O_2 \longrightarrow 2Ce^{3+} + 2H^+ + O_2 \qquad (34)$$

Oxidation/reduction reactions of Fe are responsible for colour changes in cooked and/or irradiated meat.

Protective and Sensitization Agents

Some substances are extremely reactive towards some or all primary radicals or excited molecules and will successfully compete with oxygen and other substances present in higher amounts in reactions with these species. As a result, these substances are often called scavengers. If they form relatively unreactive products they will provide protection to other radiation-sensitive materials present and generally reduce the extent of radiation damage in the system. Alternatively, if they form highly reactive radicals they may lead to enhancement of degradative reactions.

The ability of a scavenger to compete for reactive species is determined by its concentration and the rate constant for the reaction involved. Since rate constants may vary by a factor of 10^6 the influence of scavengers may be substantial. Amino acids and ascorbic acid are common protective agents in foods.

More Concentrated Solutions

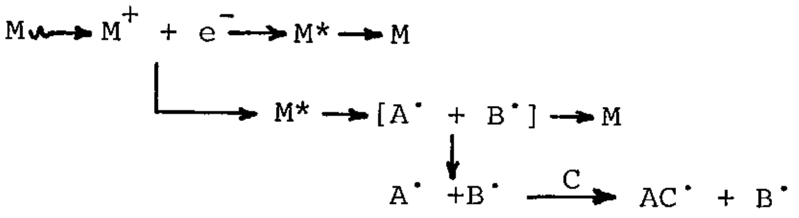
We have seen that in dilute aqueous solutions radiation chemistry is predominantly the chemistry of the primary species with each other or with solutes. When the concentration of solutes exceeds about 10^{-3}M radicals begin to be scavenged in spurs, and slightly higher product yields are obtained. At concentrations of 10^{-1} M direct effects (i.e. the direct action of radiation on the solute) may become detectable. Direct effects are important at solute concentrations above about 1M. There is much less quantitative information about direct effects than about indirect effects.

Non-Aqueous Systems

The sensitivity of organic compounds to ionising radiation, and the types of reactions involved, vary so widely that any discussion of them is necessarily general. Whereas some aromatic compounds are highly resistant to radiation others such as olefinic monomers undergo chain reactions which produce very large changes for relatively low irradiation doses. Three characteristic features of reaction in organic, non-aqueous media are discussed.

(i) Geminate recombination of ion-pairs. Because of greater recombination of the initial positive and negative ion pair (reaction 35a) $G_{(r)}$, the G value for production of radical species, is somewhat lower than in aqueous solutions, usually in the range 0.1 to 1.0 compared to about 6.5 for water.

(ii) The cage effect. Many of the primary or secondary radicals formed merely recombine giving the original material (reaction 35b). Recombination is assisted by a cage of solvent molecules surrounding the radical pair. The effect of this cage is much greater in the solid or frozen state and is responsible for the low yields of trapped radicals observed in frozen materials. A radical has to escape from the cage before reactions with molecular species can take place (reaction 35c).



(35a)

(35b)

(35c)

(iii) Energy transfer. Energy transfer is a process in which excitational energy absorbed by one component is transferred to another. In the case of a material M dissolved in a solvent S, enhancement of reaction (i.e. increased degradation in the present context) will result from the following sequence if $G_{(r)}$ is greater for S than for M (i.e. the potential energy barrier for formation S radicals is less than for M radicals)

$$M \rightsquigarrow M^* \longrightarrow S^* \longrightarrow S^{\cdot} + H^{\cdot} \qquad (36)$$

On the other hand, energy transfer from S to M results in retardation of reactions (i.e. protection) (reaction 37)

$$S \rightsquigarrow S^* \longrightarrow M^* \longrightarrow M \qquad (37)$$

In this case the transferred energy is insufficient to form $M^{\cdot}$ and the energy is eventually dissipated without producing reactive species.

Reactions of Radicals in Non-Aqueous Systems

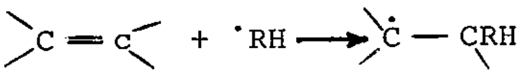
Radicals may react with each other by dimerisation (reaction 38) and disproportionation (reaction 39).

$$^{\cdot}RH + {}^{\cdot}RH \longrightarrow HR\text{-}RH \qquad (38)$$

$$^{\cdot}RH + {}^{\cdot}RH \longrightarrow R + RH_2 \qquad (39)$$

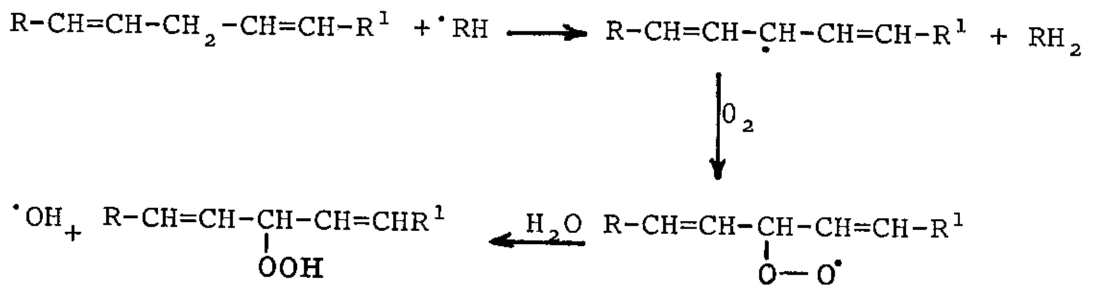
The extent of disproportionation relative to dimerisation is generally higher for more complex radicals. Disproportionation results in a product with a double bond.

Radicals react with molecules by adding to olefinic bonds (reaction 40), often the first step in a chain reaction, or may



(40)

abstract a H atom from the carbon adjacent to a double bond, with subsequent attack by oxygen leading to formation of peroxy and hydroperoxy compounds (reaction 41).



$$\mathrm{R\text{-}CH{=}CH\text{-}CH_2\text{-}CH{=}CH\text{-}R^1} + {}^{\bullet}\mathrm{RH} \longrightarrow \mathrm{R\text{-}CH{=}CH\text{-}\underset{\bullet}{C}H\text{-}CH{=}CH\text{-}R^1} + \mathrm{RH_2}$$

$$\mathrm{R\text{-}CH{=}CH\text{-}\underset{\bullet}{C}H\text{-}CH{=}CH\text{-}R^1} \xrightarrow{O_2} \mathrm{R\text{-}CH{=}CH\text{-}\underset{O-O^{\bullet}}{\underset{|}{C}H}\text{-}CH{=}CH\text{-}R^1} \qquad (41)$$

$$\mathrm{R\text{-}CH{=}CH\text{-}\underset{O-O^{\bullet}}{\underset{|}{C}H}\text{-}CH{=}CH\text{-}R^1} \xrightarrow{H_2O} {}^{\bullet}\mathrm{OH} + \mathrm{R\text{-}CH{=}CH\text{-}\underset{OOH}{\underset{|}{C}H}\text{-}CH{=}CHR^1}$$

Radicals produced in reaction 41 may also take part in polymerisation reactions. Reactions of these types lead to oxidation, rancidity and solidification of unsaturated oils. Decomposition of hydroperoxides yields a variety of alcohols, aldehydes, ketones and acids leading to colour and flavour changes. The irradiation of saturated fats in the absence of oxygen causes predominantly chain scission resulting in a variety of hydrocarbons, aldehydes, acids and esters.

Radical-radical reactions are much faster than radical-molecule reactions. They generally have low activation energies and are consequently little affected by changes in temperature. Hence radical-radical reactions tend to be favoured by lowering the temperature while radical-molecule reactions are favoured by raising it.

Comparison of Effects in Food and Model Systems

Examination of the voluminous literature shows that, generally speaking, the same chemical products are formed in foods as are formed in dilute solutions or in simple component substances. There are often however large quantitative differences. Radiation-sensitive substances such as amino acids, enzymes, sugars, anti-oxidants, β cartotene and vitamins suffer much less degradation in complex foods than in simple systems. The three main reasons for this have already been discussed.

Degradation is often greater in dilute solutions because of the concentration effect (see Figure 1). In foods degradative changes occur by a combination of direct and indirect reactions.

Radiation damage is often less in foods because of the presence of protective substances (scavengers) such as amino acids, triglycerides and ascorbic acid. Partly purified enzymes are more radiation resistant than highly purified enzymes because of the presence of the enzyme substrate and impurities which react with radicals. The extent of degradation of the protective agent itself may vary considerably from one food to another, presumably because of the presence of other protective substances in some foods.

Radiation damage is also less in foods because foods have structure which tends to restrict diffusion of reactive species and localise radiation damage. Reactions between substances in different phases or separated by cell walls are inhibited compared to those in homogeneous systems.

Although, as we have said, differences in effects are generally quantitative rather than qualitative, care is nevertheless needed in extrapolating findings from dilute solutions to foods. For example, irradiation of very dilute solutions of vitamins in water may provide a poor indication of both the extent and nature of decomposition reactions in specific foods. The reason is that the primary products of water radiolysis, namely $e^-_{(aq)}$, $H^\bullet$ and $^\bullet OH$, attack the vitamins in the dilute solutions, but in foods react predominantly with scavengers or the major components of the food such as carbohydrates and proteins. It may be the secondary radicals produced in these reactions that cause most of the decomposition of radiation-sensitive materials such as vitamins present in very small amounts. If so, a different range of products will be formed.

Minimising Radiolytic Effects in Foods

Methods used or proposed for minimising radiation effects in irradiated foods can be discussed in terms of the radiation chemistry involved. Methods that have been tried include irradiation in the frozen or dried state, irradiation in the absence of oxygen, irradiation at high dose rates, and use of radical scavengers as protective agents.

One may expect degradative reactions to be less in the frozen state because (a) a decreased rate of diffusion of primary and secondary radicals causes an increase in the proportion of radicals that recombine and (b) a decrease in temperature favours radical-radical reactions (i.e. mostly giving molecular products and terminating kinetic chains) over radical-molecule reactions (i.e. those causing degradation of food components). Studies on a variety of foods show that temperatures of about -30°C or less are usually required but further reduction of temperature provides little or no additional benefit. Presumably this is because at -30°C the diffusion of radicals is effectively halted, and the radicals become trapped. They eventually react however during storage or on subsequent warming.

Irradiation in the dried state should significantly reduce the extent of indirect reactions involving primary species from water hydrolysis, and increase the extent of direct reactions which may lead to a different range of products. In some cases, as in starch for example, water has a protective effect, presumably by favouring hydrogen atom abstraction by $^{\bullet}OH$ at the expense of main chain scission.

The presence of oxygen results in production of oxidising species such as $^{\bullet}OH$, $^{\bullet}O_2^-$, $HO_2^{\bullet}$ and H_2O_2 and oxidised species such as peroxy, hydroperoxy and carbonyl compounds. Oxygen can be excluded by packaging food under vacuum or inert gas,or removed from sealed packages by metabolic processes in the food prior to irradiation, or by the action of the radiation itself. We have seen however that, even in the absence of oxygen, radiolysis of water produces the oxidising species $^{\bullet}OH$ and H_2O_2 and a similar range of oxidised species that may lead to flavour changes. With non-aqueous components such as fat there is no simple correlation between the presence of oxygen and the extent of oxidative changes. In some cases fats show less oxidative change with storage in irradiated foods than in non-irradiated foods. Interpretation of results of different treatments and conditions is complicated by the fact that oxidative changes take place over periods of days or weeks following irradiation.

Exclusion of oxygen may enhance reductive processes such as the reaction of $e^{-}_{(aq)}$ with sulfhydryl groups on amino acids and proteins leading to hydrogen sulphide odours. Thus the benefits of excluding oxygen are uncertain since the effects vary from one food to another and depend upon the irradiation dose, the conditions of irradiation and storage and the storage time.

Irradiation at high dose rates produces high concentrations of radicals which, in dilute solutions at least, favours second order radical-radical reactions at the expense of pseudo first-order radical-solute reactions. Unfortunately application of the principle to foods generally has not achieved the desired result. Often there is no noticeable difference between results for electron irradiation and those for gamma irradiation, and hence no dose-rate effect. In other cases somewhat contradictory results are obtained. One study, for example, found an inverse relationship between dose rate and peroxide formation in lard, but a similar study involving unsaturated fats found this effect to be temporary, and a few days after irradiation peroxide values were similar for all dose rates.

Minimisation of flavour and colour changes in irradiated foods has been attempted by treating foods before or after irradiation with a wide variety of inorganic and organic substances. The results are, on the whole, disappointing, although some success with some foods has been obtained using ascorbic acid or ascorbate/polyphosphate dips.

Possibly a better understanding of the basic chemistry may lead to protective substances for particular foods. These substances should be reactive towards secondary radicals produced from major constituents such as carbohydrates and proteins, not just with oxygen and highly reactive primary species. On the other hand, many foods already contain natural antioxidants and radical acceptors, and the scope for increased protection using additives may be limited by the heterogenicity and cellular structure of the food. Only further work will tell whether specific agents can be found or developed that will provide protection against flavour and odour changes in foods during irradiation and subsequent storage.

LECTURE 10

BASICS OF RADIATION MICROBIOLOGY FOR FOOD PROTECTION

P. WILLS

AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

BASICS OF RADIATION MICROBIOLOGY FOR FOOD PROTECTION

P. A. WILLS
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INTRODUCTION

Microbes are normally present in unprocessed foods, as well as in many processed foods. Their mere presence in a food generally does not present a health risk, nor does it result in overt spoilage. The risk lies in the capacity of undesirable micro-organisms to multiply in certain foods and cause either food poisoning or food spoilage. The lethal effect of ionizing radiation on micro-organisms, which may either eliminate pathogenic bacteria or reduce the effective rate of multiplication of spoilage bacteria, forms the rationale for ionizing energy treatment of many foods.

In this lecture the microbiological basics of food poisoning, food spoilage, and ionizing energy treatments are presented, factors influencing the microbial resistance of ionizing radiation, including the use of physical agents for combination treatments, are briefly reviewed, and parameters involved in dose selection are considered. Further information may be obtained from the selected references cited.

FOOD POISONING

Food poisoning caused by micro-organisms falls into two main categories.

Food-borne Infections

Food-borne infections from eating contaminated food or drinking contaminated water cause illness by microbial invasion of the host or by release of toxins produced when the food-borne bacteria have grown in the intestinal tract or some other organ. Food-borne infections can be triggered by relatively high numbers of the following genera of bacteria: *Salmonella*, *Shigella*, certain strains of *Escherichia coli*, *Vibrio parahaemolyticus*, *Yersinia enterocolitica*, *Campylobacter fetus, subsp. jejuni*, *Clostridium perfringens*, *Bacillus cereus*. Although 10^6 organisms per gram of food are normally required to cause bacterial enteritis symptoms in people, it is well to remember that in certain circumstances the minimum infective dose may be as low as 1 to 10 organisms, as the infectious dose can be affected by the diet, physical condition and immune status of the consumer as well as by other factors (Mossel, 1982).

Food-borne Intoxications

Food borne intoxications cause illness when toxins synthesized in a food by the multiplication and metabolism of certain micro-organisms are absorbed via the intestinal tract of the consumer. Organisms which are responsible for food-borne intoxications are: *Clostridium botulinum*, *Staphylococcus aureus*, *Bacillus cereus*, *Pseudomonas cocovenenans*, several species of bacteria which metabolize amino acids to form "pressor" amines (histamine, tyramine, and phenylethylamine), and many types of moulds synthesizing mycotoxins. Generally 10^4-10^5 viable cells per gram or ml of food are needed for exotoxins to be released into the food but, as with food-borne infections, other factors may influence the minimum infectious dose.

Infectious Disease Transmission

Other infectious diseases may be transmitted by foods, often after consuming very low numbers of cells only. Examples of micro-organisms, protozoa, and helminths (worms) which may be spread through food are: *Corynebacterium* *diphtheriae*, Group A streptococci, *Coxiella burnetii* (causes Q fever), Hepatitis A virus and other viruses (e.g. Norwalk), *Toxoplasma (Isospora)*, *Entamoeba histolytica*, *Giardia lamblia*, *Taenia saginata* and *T. solium* (tapeworms), *Trichinella spiralis*, *Echinococcus* (hydatidosis), *Anisakis marina* (herring worm disease), *Capillaria philippinensis* (nematode).

Prognosis

Many of the potential pathogenic hazards associated with contaminated food are removed when food is properly processed, properly stored, and properly cooked before consumption. Nevertheless, food poisoning episodes often occur and can be expected with increasing frequency and severity because of changes to intensified animal husbandry practices and large scale production of food to cater for the trend in Western Societies towards increased consumption of meals outside the home.

The number of recorded cases of salmonellosis in the Netherlands increased 13% from 1978 to 1981 (Mossel, 1982). However, it is difficult to obtain accurate figures for the current incidence of food-borne diseases, and under-reporting by 90 to 99% has been suspected (Mossel, 1982). Reported cases of isolation of salmonellae sp. from humans numbered 9000 in the Netherlands and about 25,000 in the USA in 1980. Economic losses in the USA were estimated at US$300,000,000 (Kampelmacher, 1982).

MICROBIAL SPOILAGE OF FOODS

Microbial spoilage occurs in different foods when various organisms develop and cause undesirable biochemical changes in the food. The spoilage pattern is generally characteristic for a specific food and the post-harvest handling conditions and will be dealt with in detail in other lectures. However, in general terms, according to Mossel (1982) the microbial spoilage pattern is the net result of four groups of parameters which limit or permit proliferation of micro-organisms. These parameters are intrinsic factors of the physical, chemical, and biological properties of the food, food processing modification of the initial microflora, extrinsic factors of the storage environment of the food, implicit factors influencing the organisms selected through the other three parameters. These parameters will be briefly considered.

Intrinsic Factors in Food Spoilage

These are water activity, acidity (pH), oxidation reduction (redox) potential, nutrients, natural inhibitors.

Bacteria need water to multiply in food. If the moisture content of foods is reduced, either by drying or by adding solutes such as salt, sucrose, or a gelling agent to bind the water, and "free" water is unavailable to the bacteria for replication. Water activity, a_w, of a food is the ratio of the water vapour pressure over a food to the vapour pressure of pure water, which is taken as 1.00. There is a a_w limit below which different groups of micro-organisms cannot function normally, although they remain viable (Fig. 1). Thus although bacteria cannot develop when the a_w is less than 0.87, moulds and certain yeasts can continue to proliferate unchecked by multiplication of bacteria.

Most bacteria grow best at near neutral pH whereas yeasts and moulds grow best under acid conditions. The inability of Clostridium botulinum to grow below pH 4.5 means that acid canned foods can be processed at lower temperatures than those normally used.

Spoilage or pathogenic bacteria may proliferate best in the presence of oxygen, or in a limited supply of oxygen, or in the absence of oxygen. The way that foods are stored and packed can therefore affect the type of spoilage organisms that will survive and multiply.

Microbial spoilage also depends on the ability of the invading bacteria to use the chemicals in the foods as substrates. This generally means that the organisms with the appropriate enzymes prefer for example amylolytic, proteolytic, or pectolytic enzymes for spoilage of starches, meats, or fruits respectively. The presence of naturally occurring bacterial inhibitors in foods does not automatically prevent spoilage because generally organisms resistant to the inhibitors are also present.

Influence of Processing in Food Spoilage

Heat treatment is the most common processing method in commercial use, followed by the addition of chemical preservatives such as sulphur dioxide or benzoic or sorbic acids. Ionizing energy treatment will be discussed separately.

Extrinsic Factors in Food Spoilage

Foods stored at chill temperatures will eventually spoil from proliferation of psychrophilic and psychotrophic organisms whereas no microbial growth will occur in foods frozen at about -20°C, rather non-spore-forming organisms will be slowly inactivated at this temperature.

The effect of water vapour pressure during storage on spoilage can be complex and may be influenced by the nature of the food, packaging, moisture content of the food, the a_w gradient, changes in day and night temperatures.

Oxygen depletion and increased partial pressure of carbon dioxide in vacuum packaged foods also affect microbial spoilage. It is important to be aware that anaerobic organisms may grow under aerobic conditions and vice versa.

Implicit Influences on Microbial Spoilage

These may be: different growth rates for organisms of different genera; synergistic growth between groups of micro-organisms caused by increased availability of nutrients or favourable changes in pH, redox value, a_w, elimination of antimicrobial substances, collapse of biological structure; antagonism between microorganisms caused by competitive utilization of nutrients, changes in pH and in redox potential, formation of antibacterial substances, lysis by phages (Table 1).

TABLE 1. ANTAGONISM BETWEEN FOOD PATHOGENS AND SPOILAGE ORGANISMS IN FOODS*

PATHOGEN	ANTAGONIST	
Cl. botulinum	*B. subtilis*	*Brevibact. linens*
	Cocci	*Cl. sporogenes*
	Str. lactis	*Enterobacteriacea*
	Ps. aeruginosa	*Lactobacillaceae*
Cl. perfringens	*Lactobacillaceae*	*Cl. sporogenes*
	Streptococci D	
Salmonellae	*E. coli*	*Pseudomonas* spp
Staph. aureus	*Aeromonas*	*Enterobacteriaceae*
	Bacillus sp	*Lactobacillaceae*
	Streptococci	*Staph. epidermidis*
	Pseudomonas	Acinetobacter

(Mossel (1982))

MICROBIOLOGICAL BASIS FOR IONIZING ENERGY TREATMENTS OF FOOD

Food preservation methods aim to exert some degree of control over the normal progression of microbial growth in foods for the purpose of delaying or eliminating spoilage or preventing the transmission of food-borne diseases. All these objectives can be achieved with ionizing energy treatment of foods.

Radurization ("radiare" = to radiate, "durare" = to prolong) eliminates some spoilage organisms, thereby reducing total microbial numbers with a consequent extension of the shelf-life of the product. The process is comparable to heat pasteurization.

Radicidation ("radiare" = to radiate, "caedere" = to kill) eliminates all of a specific type of organism which can cause spoilage or food poisoning, thereby reducing the risk of consuming food pathogens.

Radappertization eliminates all organisms from foods or packaging materials to produce a sterile product. The process is comparable to canning.

Biological contaminants of foods vary in resistance to the lethal effects of ionizing energy. Resistance increases inversely with size from parasites, moulds, bacteria (excluding spores), yeast, bacterial spores, with viruses generally being the most resistant. However, within these classes, exceptions and overlapping occurs.

Microbial cells subjected to ionizing energy may continue to respire and move around and may even divide a few times. However, unless they can continue reproducing in a nutrient medium sufficiently to produce colonies, they are regarded as having been inactivated. Loss of colony-forming ability is thus usually taken as the criterion for cell death.

Decimal Reduction Dose (D_{10})

To quantify the sensitivity of organisms to ionizing energy, the number of colony-forming units surviving different doses is used to construct semi-logarithmic plots of the fraction of organisms surviving at different doses (Fig. 2). Similar plots are used to study the resistance of micro-organisms to heat or ethylene oxide or other chemicals.

The radiation resistance of a particular organism tested under specific conditions is determined by the slope of the straight line portion of the graph, as the decimal reduction dose, or D_{10} or D value. The D_{10} dose is the amount of absorbed radiation (dose) needed to reduce the population by 90%, and thus to achieve a 10% survival level of the organisms initially present. It is therefore equivalent to the dose which will reduce the fraction of surviving organisms by one log cycle.

The higher the D_{10} value, the more resistant the organism is to ionizing radiation. However, D_{10} values are not immutable as the resistance of a specific organism can depend on a number of factors. Tables in textbooks which list D_{10} values can therefore be misleading.
An alternative method is used in Table 2 where D_{10} values have been used to group food pathogens and spoilage organisms into different radiation sensitivity classes.
An organism may belong to more than one class as its D_{10} varies with environmental or other factors.

TABLE 2. COMPARATIVE RADIATION RESISTANCE OF FOOD ORGANISMS

ORGANISM	D_{10} RANGE (kiloGray)			
	0.03-0.25	0.25-0.8	0.8-1.7	1.7-8
	SENSITIVE	MOD.SENS.	MOD.RES.	RESISTANT
Vibrio	│			
Yersinia	│			
Campylobacter	│			
Pseudomonas	│	│		
E.coli	│	│		
Salmonella	│	│	│	
Staphylococcus	│	│	│	
Penicillium		│	│	
Aspergillus		│	│	
Micrococcus		│	│	│
Saccharomyces			│	│
B.coagulans			│	│
B.stearothermophilus				│
B.cereus				│
Cl.sporogenes				│
Cl.perfringens				│
Cl.botulinum				│
Viruses				│

Fortunately, most microbial food pathogens, except for bacterial spores and viruses, are sensitive or moderately sensitive to the effects of ionizing energy. A few food-borne organisms, such as *Micrococcus radiodurans* and *Moraxella/Acinetobacter* sp. have been isolated with a very high resistance to ionizing radiation. The survival of these very resistant organisms after moderate doses of ionizing energy is not considered to be a public health hazard.

Effect on Cells

Different food pathogens vary in their resistance to ionizing energy because of inherent differences in:

(1) Amount of water in the cytoplasm
(2) Number of nuclei in the cell
(3) Structure of the chromosomal DNA and its association with repair and degradative enzymes. The base composition of the DNA does not determine radiation resistance. Thus the guanosine-cytosine content of DNA from very resistant *M. radiodurans* and very sensitive *Pseudomonas* organisms is the same 67%.
(4) Size of the chromosomal DNA target

In general, the susceptibility of a cell to the adverse effects of ionizing energy can be inversely correlated with the amount of DNA in the cell. The smaller the organism, the greater its resistance. However, differences in radiation sensitivity within a class or species may simply reflect the presence or absence of efficient mechanisms within the cell for repairing radiation-induced damage to the DNA.

Ionizing energy may affect cells either (1) directly or (2) indirectly through free radicals or other radiolysis products formed from liquids surrounding the cell or the vital components within the cell.

The primary "target" for the ionizing energy is most probably the cell's DNA. The association of the DNA with the cytoplasmic membrane is an important secondary target for ionizing radiation. Many DNA repair enzymes are located in the membrane .

The mechanism of radiation damage to the DNA molecule is unclear. Covalent bonds may be broken with a loss of purine or pyrimidine base, leading to a lethal mutation, or the chain may break.

Single strand breaks in the DNA molecule have been measured in bacteria and many other types of cell after exposure to ionizing energy. Breaks in adjoining strands (double strand breaks) generally, but not always, result in cell death.

The fate of single strand breaks varies with environmental conditions and the presence or absence of different enzymes. Strand breaks may be repaired by several different mechanisms, some or all of which also operate when organisms are damaged by heat or chemicals. There is nothing special about the way bacteria respond to the effects of ionizing energy.

FACTORS INFLUENCING RADIATION RESISTANCE OF MICRO-ORGANISMS

The lethal effects of ionizing energy may be influenced by alterations in the environment before, during, and after treatment. Thus different doses of radiation may be required to achieve the same degree of bacterial safety in products prepared or packaged in different ways. Factors which affect radiation resistance include growth phase, gaseous atmosphere, temperature, water activity, dose rate, radiosensitizers, radioprotectants, sub-lethal injury, combination treatments with physical agents. Complex interactions between factors may also occur. A summary of some of the chief effects of these factors on radiation resistance follows.

Growth Phase

Bacteria in the exponential growth phase are generally most sensitive to ionizing energy. Resistance is highest in the lag and stationary phases. However, the reverse situation has been reported for a very resistant organism. Resistance is much greater when bacteria are transformed to dormant spores with part, but not all, of this resistance being lost on germination.

Gaseous Atmosphere

Bacterial sensitivity increases two to five-fold if oxygen is present during treatment. If linear accelerators are used as the source of ionizing energy, atmospheric oxygen within the field is converted to ozone and treatment is therefore substantially anoxic, irrespective of whether or not the product has been vacuum packaged. For dry foods, sensitivity is also influenced by the post-treatment atmosphere. Inactivation is greater when bacterial spores are exposed to oxygen after treatment.

Temperature

The temperature at which a product is treated with ionizing energy may influence the resistance of microorganisms. Experiments with suspensions of pure cultures of microorganisms at temperatures down to -180°C have shown that the organisms were up to seven or eight times more resistant than when at 25°C. This increase in resistance at low temperature occurs because much of the ability of ionizing energy to harm bacteria indirectly through powerful radiolytic products produced in water is lost with freezing. Inactivation will therefore be limited to that mainly resulting from ionizing energy acting directly on microbial DNA.

Microbial resistance in frozen foods is increased about two or three-fold, compared with resistance at ambient temperature. The D_{10} of Staphylococcus aureus suspended in chicken purée rose from 0.17 kGy at 25°C to 0.57 kGy at -20°C (Fig. 2).

By contrast, bacteria become more sensitive when ionizing treatment is carried out at higher temperatures. This is thought to occur because the repair systems which normally operate at ambient or slightly above ambient temperatures are damaged at higher temperatures.

Water Activity (a_w)

Just as freezing protects bacteria against the lethal effects of ionizing energy, so does a reduction in the moisture content (a_w) of the food. The absorption of ionizing energy in foods of low a_w results in lower concentrations of harmful radiolysis products than in similarly treated high a_w foods.

Bacterial spore resistance appears to be less affected by changes in a_w than vegetative cell resistance. The influence of a_w of different foods and food ingredients on the resistance of specific food pathogens has received little attention.

Dose Rate

For a specific preservation application, the time needed to treat foods could vary from seconds to several hours, depending on whether treatment was undertaken in a facility using a machine or isotopes as the ionizing energy source. It could therefore be important to know whether radiation resistance of bacteria is affected by the rate at which a specific dose is absorbed into a food. This question remains unresolved, with opposing evidence suggesting that electrons are about 10% less efficient than gammas, or the reverse, or that there is no difference between them.

In theory, it is possible that a small irradiator with a very low isotope loading, such that the dose rate was less than 30 Gy h^{-1}, could create a problem for certain foods treated in the summer. If the food is a good culture medium, the multiplication rate of certain organisms might be higher than the rate at which they can be inactivated. In practice, this situation would be most unlikely to occur because the economics of radiation processing would be too unfavourable.

Radiosensitizers

Many experiments have been carried out to find chemicals which could be added to food to sensitize micro-organisms to the effects of ionizing energy. The theory is that it should then be possible to reduce the dose needed to inactivate the organism and thus help to maintain the organoleptic and essential characteristics of the food. The problem is that food, by its very nature, contains the kind of molecules which may either scavenge free radicals capable of damaging bacteria or else react with the added chemical or its radiolytic products.

The choice of chemicals suitable for testing as sensitizers has generally been based on mechanisms proposed for how the chemicals would act, such as suppression of sulphydryl groups, adverse effects on repair processes, oxygen mimics, abstraction of electrons from ionized biomolecules, production of radiolysis compounds toxic to micro-organisms. In practice, few of the chemicals proposed could be considered suitable additives for foods. However, some success as radiosensitizers has been obtained with sodium chloride and other alkali halides, sodium nitrite and nitrate, and also sorbates.

For fundamental reasons, the degree of sensitization cannot exceed that obtained with oxygen, that is, about a two to four-fold increase in sensitivity. This limitation suggests that combinations of ionizing energy with physical agents could be more effective treatments for promoting radiosensitization.

Radioprotectants

The lethal effect of bacteria in liquid suspension may be reduced in the presence of certain chemicals such as hydrogen sulphide, aliphatic alcohols, glycerol, sucrose, dimethyl sulphoxide, thiourea. These chemicals act by reducing the oxygen content or the water activity level. With the possible exception of sucrose, none of these chemicals could be considered as normal food additives.

Sub- lethal Injury

Sometimes micro-organisms become damaged after treatment with higher doses of ionizing energy. This may also happen to organisms after freezing or heating. The practical effect is that colonies may not be formed under standard plating conditions and special recovery procedures may be needed to allow the injured cells to repair before enumeration takes place. If these are not carried out, the organism will appear to be more sensitive to ionizing energy than it actually is.

Sub-lethal injury may be detected if exponential survival curves began in depart from linearity and become more convex at higher doses, so that it appears that the D_{10} value is decreasing with increasing dose. These types of curves are also seen if inhibitory amounts of food substrate are present in the dilution being plated. They are misleading optical illusions, theoretically impossible, and should always be investigated.

COMBINATION TREATMENTS WITH PHYSICAL AGENTS

The rationale for combining ionizing energy treatment with physical agents to preserve foods is to increase the lethal effectiveness of the radiation, save energy, reduce costs, reduce throughput times, maintain food quality. The physical agents which have been investigated include heat, UV,and hydrostatic pressure. Mild to moderate heat appears the most promising.

Heat

A combination of mild heat and ionizing energy can produce a lethal effect which is synergistic, the effect being greater than the additive effect of the two agents acting independently. The order in which the treatments are supplied influences the result and may depend on the species of organism. Thus inactivation is synergistic when fungal spores are mildly heated and then irradiated. The synergistic effect decreases with increasing delay between treatment. However, for bacterial spores synergism only occurs if the spores are irradiated first and then heated, or if the treatments are simultaneous. Ionizing energy can induce germination-like changes in dormant spores and in this form the spores are more heat sensitive.

A much greater synergistic effect has also been noted when irradiated bacterial spores are heated at 80°-90° and up to 500,000-fold increases in spore inactivation have been reported. It has been suggested that the synergistic effect may be due to lethal heat inactivating repair enzymes.

UV

The possibility of preserving foods with a combination of non-ionizing (UV) and ionizing radiations (gamma or electrons) has been investigated. Further work is needed to clarify the efficiency of this combination.

Hydrostatic Pressure

The dose required to inactivate bacterial spore contaminants of liquids or semi-solid foods may be considerably reduced if applied after moderate hydrostatic pressure treatment carried out at the optimum conditions for maximum (99.9%) inactivation of the particular spore species. Some, but not all, non-spore-forming organisms are also inactivated at similar pressures.

Pre-irradiation compression of sugar solutions experimentally inoculated with B. pumilus spores and the sorbate-resistant yeast Saccharomyces bailii effected about 50% reduction in the dose needed to inactivate 10^6 organisms (Table 3).

TABLE 3. COMBINATION HYDROSTATIC PRESSURE/IONIZING ENERGY TREATMENT FOR DECONTAMINATION OF SUGAR SOLUTIONS

TREATMENT MPa/°C/min	10^6 INACTIVATION DOSE (kGy) B.pumilus	 S.bailii
-	18.4	4.5
105/52/8	10	-
276/10/5	-	2.25

CHOICE OF DOSE

The selection of dose will be influenced by:

(1) microbiological objective, for example, pasteurization, decontamination, elimination of a specific pathogen, or elimination of all microbes

(2) number of organisms causing concern per product unit

(3) D_{10}, of the organism(s) causing concern under the prevailing test conditions

(4) degree of assurance needed that the dose will achieve the objective

The effect of batch size on dose needed for sterilization or elimination of specific pathogens is shown in Table 4. In this hypothetical exercise, the objective is to select a dose which will ensure that not more than one organism survives in either 1, 10^4, or 10^6 packets of a product contaminated by a single type of food pathogen at the level of 100 organisms per unit. Each packet therefore contains 100 organisms. The contaminant has a D_{10} value of 3 kilogray when tested in the product. The total number of contaminants surviving each increment of 3 kGy is shown in Table 4.

TABLE 4. EFFECT OF DOSE ON REDUCTION IN BACTERIAL NUMBERS

DOSE	NUMBER OF ORGANISMS IN BATCH CONTAINING N UNITS (PRE-TREATMENT COLONY-FORMING ORGANISMS PER UNIT = 100; D_{10} = 3kGy)		
		N	
(kGy)	1	10 000	1 000 000
0	100	1 000 000	100 000 000
3	10	100 000	10 000 000
6	1	10 000	1 000 000
9	0.1	1 000	100 000
12		100	10 000
15		10	1 000
18		1	100
21			10
24			1

This table clearly demonstrates the relationship between batch size and the dose needed to eliminate organisms to a specified level per batch. For units of equal contamination levels, to assure that not more than one organism is left in one unit per batch, a dose of 18 kGy would be required if the batch size is 10,000 units or 24 kGy if the batch size is one million units. Thus absence of growth in small samples tested at a particular dose is a quite inadequate and misleading basis for selecting the dose required to achieve the same objective in larger volumes of material.

By contrast, the dose needed to reduce the number of organisms to a constant level per gram or other unit of product is independent of batch size. Thus, in the example given, 6 kilogray would ensure a contamination level of one organism per packet irrespective of whether one or one million packets was treated.

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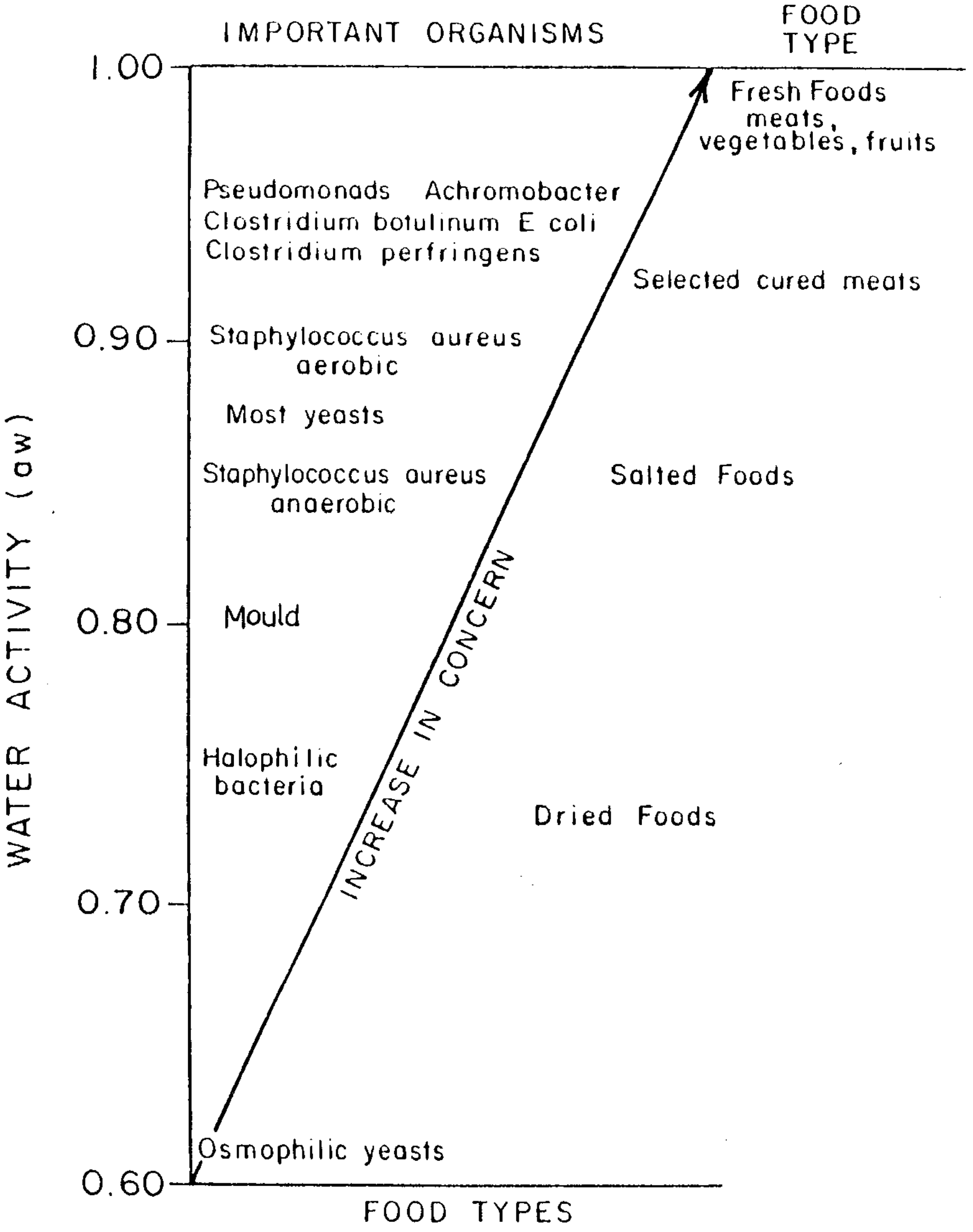
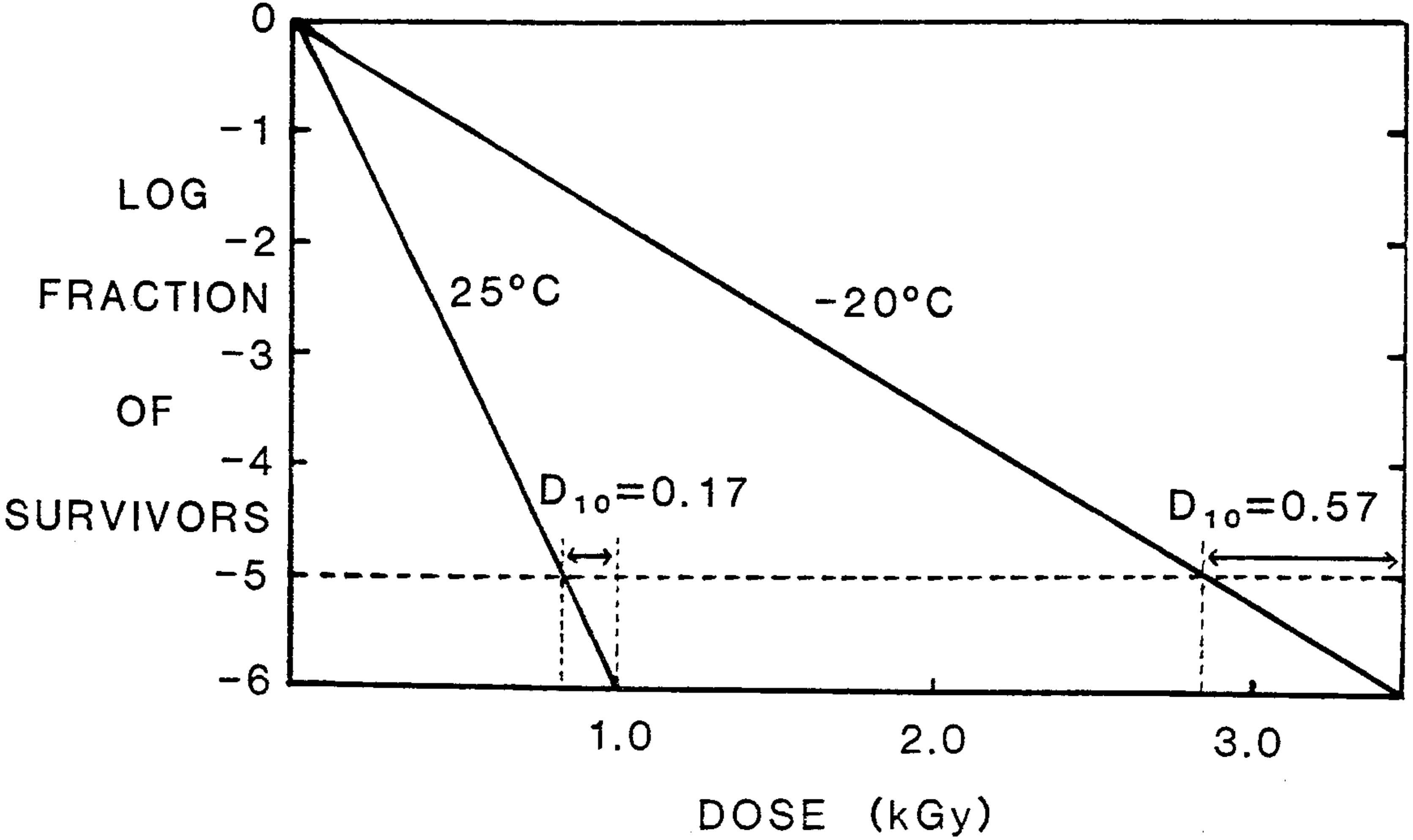


FIG. 1. MINIMUM a_w LEVELS OF IMPORTANT ORGANISMS INVOLVED IN SPOILAGE AND FOOD SAFETY

FIG. 2 EFFECTS OF TEMPERATURE ON RADIATION RESISTANCE OF STAPHYLOCOCCUS AUREUS SUSPENDED IN CHICKEN PURÉE.



LECTURE 11

IONISING TREATMENT OF FOOD - DISINFESTATION ENTOMOLOGY

E. SHIPP

IONISING TREATMENT OF FOOD - DISINFESTATION ENTOMOLOGY

E. Shipp
Associate Professor
School of Zoology, University of New South Wales
Kensington, N.S.W. 2033

SUMMARY

The main insects for which this type of treatment may be considered belong to three broad groups, the Coleoptera (beetles), the Lepidoptera (moths) and the Diptera (flies). The desirable effects of ionizing energy on insect pests include reproductive sterilisation as well as killing. The dose levels required for the former are generally considerably lower than for killing. As mortality may, at lower doses, be by starvation, due to damage to cells of the alimentary canal, death is generally not immediate, but may be delayed for a number of days. This may be a disadvantage for this method of control, especially if the product is for immediate export and there is a NIL live insect requirement. Lepidoptera are generally more resistant to irradiation than Coleoptera or Diptera.

INTRODUCTION

Ionizing energy produces many types of chemical change in an insect's body. However, following the application of low doses, cells of various tissues may survive until they attempt to divide, at which time they may die, apparently due to failure of the chromosomes to replicate and separate sucessfully. For this reason the most sensitive tissues are those containing a high proportion of dividing cells. In insects, the midgut region of the alimentary canal contains many active cells that are involved in the secretion of digestive enzymes and absorption of digested food materials, and these cells wear out and die relatively quickly. These active cells are then replaced from groups of constantly dividing "regenerative" cells. When irradiation prevents enough of these regenerative cells from dividing successfully, the insect will die, effectively from starvation. The reproductive organs, the gonads, also contain many dividing cells, especially at certain times in the life cycle. They are often even more susceptible to irradiation than the midgut, resulting in reproductive sterilisation following relatively low doses. At higher doses other tissues may also be damaged, leading to more rapid mortality.

THE INSECTS

Virtually all insect pests of stored products are potentially susceptible to control by ionizing energy. The species for which a considerable body of susceptibility information is available include the following;

COLEOPTERA, *Sitophilus* spp. (granary and rice weevils), *Tribolium* spp. (flour beetles), *Oryzaephilus surinamensis* (sawtoothed grain beetle), *Stegobium paniceum* (drug store or biscuit beetle), *Lasioderma serricorne* (tobacco beetle).

LEPIDOPTERA, *Cadra cautella* (tropical warehouse moth), *Anagasta kuehniella* (Medit. flour moth), *Plodia interpunctella* (Indian meal moth,dried fruits,nuts,etc), *Sitotroga cerealella* (Angoumois grain moth).

DIPTERA, *Dacus tryoni* (Qld. fruitfly).

As the common names indicate, a wide range of products is involved.

DOSAGE LEVELS

1. Reproductive sterilisation

Both sexes may be sterilised by ionizing energy, though they are not necessarily equally affected by a given dose, as shown in laboratory experiments where treated insects of one sex can be mated with untreated virgin insects. In the normal field situation, where both sexes will be treated together, partial sterilisation of each sex will contribute to the overall reduction in progeny. The dose/response curve is broadly exponential in form, when the number of progeny from treated parents is expressed as a percentage of the progeny produced by untreated control insects under similar conditions. If it were a truly exponential relationship complete sterilisation should never be achieved. However, large scale experiments, involving millions of insects, have confirmed that complete sterilisation does occur at doses predicted from small scale laboratory experiments. Fruitfly pupae treated with about 100 Gy (10 Krads) result in sterile adult flies. Adult beetles generally require less than 200 Gy for sterility, while moths are somewhat more resistant. The precise dosages required depend on a number of factors, as indicated below. At dosages that just prevent progeny production soon after treatment, there may be some recovery of fertility with time.

2. Lethality

Insecticides are generally expected to kill insects within hours of application and mortality counts are commonly made at 24 hours. With ionizing energy the situation is rather different and it may be useful to consider what is meant by "killing" in this case. The normal longevity of *Tribolium* beetles, for example, is generally over six months. If a certain dose reduces the lifespan of all the treated beetles to a few weeks, it may reasonably, biologically speaking, be considered to have killed them, especially as during that time they will have fed very little if at all, and it is unlikely that any fertile eggs would have been laid. The lowest dose to reduce survival in this way may be called the minimum lethal dose (about 80 Gy for *Sitophilus* spp. or 180 Gy for *Tribolium* spp.). Following treatment with this dose there may be no deaths for some days (8 for *Sitophilus* spp. or 12 for *Tribolium* spp.) and this may be referred to as a latent period. After this delay the survival curve is sigmoid in form, all the beetles being dead by 21 or 27 days. In relation to immature stages a minimum lethal dose would prevent completion of development to the adult form.

Following treatment with doses below the minimum lethal level, as defined above, some mortality may occur, the amount depending on the actual dose level. Any such mortality will occur only after a similar latent period and for the same duration as following the minimum lethal dose. Thereafter mortality drops to a low level, especially at low doses where survivors may actually live longer than untreated controls. However it should be remembered that feeding by these survivors is considerably reduced, their metabolic rate is lower, and they produce fewer offspring.

As the applied dose is increased above the minimum level, the latent period is progressively reduced and the slope of the curve becomes steeper. To produce mortality in times comparable to those expected following insecticide treatment may require doses of ionizing energy at least an order of magnitude greater than the minimum lethal dose. Fortunately this fast kill is rarely necessary.

Using data from the survival/time family of curves for a given species tested under a particular set of conditions, it is possible to determine the most suitable time after treatment for mortality counts from which to derive dose/mortality curves. Above a threshold dose level, this relationship produces a sigmoid curve which is similar in form to the curves resulting from insecticide tests. It can thus be transformed to log dose and probit mortality (a straight line relationship - more readily susceptible to statistical analysis and comparison than the original curve) to give LD_{50} and other parameters.

FACTORS INFLUENCING EFFECTIVENES

A. Extrinsic factors

Dose rate. Some of the damaging changes, caused by ionizing energy, can be repaired by the cells, but this takes time. Thus if a certain total dose is applied at a slow rate there is more time for recovery to take place before the end of the application than if the same total dose is applied at a faster rate. Higher dose rates are generally more effective for both killing and sterilising, than lower rates for the same total dose. However at very high dose rates, such as those available from electron beam systems, this may no longer apply (there is insufficient time for appreciable recovery to occur) and there may be an optimum dose rate for effectiveness. Fractionated doses tend to be less effective than the same total dose applied continuously.

The gaseous environment. Anoxia and low levels of oxygen, induced by flushing the atmosphere with nitrogen or carbon dioxide, generally reduce the effects of ionizing energy treatments.

Temperature. Higher temperatures,within the range 15-30° C, during irradiation tend to decrease the effectiveness of the treatment, apparently by increasing the metabolic rate and thus the amount of recovery. However higher temperatures after treatment generally increase it's effectiveness.

Food. When Tribolium are reared on highly refined flour there is a relatively high larval and pupal mortality, development is slow and the resulting beetles are small. However these beetles are more resistant to ionizing energy than beetles reared on more nutritious wholemeal flour. Presumably this is due to differences in metabolic rate.

B. Intrinsic factors/susceptibility.

Stage of life cycle/age. Eggs are generally the stage most susceptible to the lethal effects of ionizing energy. Insects gradually become more resistant as they develop through the immature stages to the adult form. Only from the later larval stages, when the gonads begin to mature and the germinal cells divide, does it become possible to differentiate a sterilising dose of irradiation from a lethal dose.

Sex. Differences between the sexes, in mortality following irradiation, are generally not significant. However the dose required to produce sterility is often higher for males than for females. Commonly all sperm are matured during the early adult life of the male, and there may be no further germinal cell divisions, whereas cell division to produce eggs generally continues throughout the productive life of the female insect.

GENERAL CONSIDERATIONS

Comparison of ionizing energy and insecticidal chemicals

Residues. Ionizing energy, in common with other physical methods (heating, cooling), carbon dioxide and inert gases (eg nitrogen), does not leave any toxic residues that may harm later consumers. By the same token only insects present at the time are killed, there being no residual effect as generally required of insecticides in grain protection. Fumigants act in a similar manner, though in some cases these may leave toxic residues.

Resistance. There is no evidence that insects can develop significant resistance to ionizing radiation. As insects develop higher levels of resistance to more and more insecticides, the prospect of alternative methods of control, including ionizing energy, may become more attractive.

Underdosing. If the actual doses of ionizing energy fall short of the levels required for complete mortality, the surviving insects will almost certainly be sterile. This means that the existing population is in effect wiped out. But it also means that while any of these insects remain, they may mate with any newcomers, thus reducing their progeny. This is along the same lines as the Sterile Insect Release Technique which has been used to eradicate certain insect pests, and has been considered to be technically feasible for control of stored product insects. The situation with low doses of insecticides is quite different.

Safety margins. The doses of ionizing energy required to produce any undesirable effects in grain are generally two orders of magnitude greater than the levels necessary to control insect pests in it. However off-flavours may be produced in oranges by about twice the dose that will prevent fruitfly adults from emerging from treated fruit. This is little better than the situation with presently used fumigant treatments, though these may also leave undesirable residues. This may be particularly important for export considerations.

Applicability. Although recent developments in electron beam (E.B) technology may reduce capital costs, the magnitude of these generally mean that ionizing energy treatment is only suitable for situations where relatively large amounts of a product, or broadly similar types of product, are to be treated. Such products would include bulk grain, tobacco, fruit (oranges), dried fruit, nuts, processed cereals, etc. After packaging, it may be necessary to use gamma irradiation, rather than E.B., because of its greater penetration.

Cost effectiveness. Because of the high capital cost of installing equipment for ionizing energy treatments, including shielding systems, the cost of this method of control has generally been considered to be high relative to insecticide use. However the intrinsically higher cost of some of the newer insecticides, which are rendered necessary by the development of resistance to formerly used chemicals, may be changing this relativity. Increasingly stringent controls on residues may make ionizing energy more attractive in some areas in the not too distant future.

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LECTURE 12

AUSTRALIAN AGRICULTURAL QUARANTINE

IMPORTS & EXPORTS

J. TURPIN, B. READ,
R. PINSON, G. HIGGS

AUSTRALIAN AGRICULTURAL QUARANTINE - IMPORTS AND EXPORTS

Presentation by N.S.W. Department of Agriculture Officers:
J.W. Turpin, Director, Plant Regulatory Services
B.J. Read, Scientific Officer (Regulatory)
R.S. Pinson, Senior Agricultural Inspector, Quarantine
G.M. Higgs, Senior Agricultural Inspector, Exports & Standards

The inspection of goods imported into or exported from Australia is basically to meet the quarantine requirements of Australia and countries with which we trade. Therefore, the principles of inspection and treatment are similar for both with products of similar quarantine risks.

Generally a much wider range of controls must be exerted over imports to give the degree of quarantine security necessary to protect our agricultural, pastoral and forestry industries. Quarantine policy with imports is based on an assessment of risk factors, including the goods, possible contamination, the pest or disease status of the exporting country, and acceptable treatment procedures. However, with both animals and plants introduced into Australia, post-entry quarantine is necessary to prevent the introduction of new diseases.

With exports, the aim is to meet the international health requirements for general freedom from pest and disease and also any additional requirements of the importing country. In addition, standards are set for export quality to ensure the product is sound, wholesome and of good appearance. These aim to protect Australia's good name as an exporting nation.

CO-OPERATIVE ARRANGEMENTS FOR INSPECTION - COMMONWEALTH/STATES

The Commonwealth Department of Primary Industry is responsible for the two Acts administering both imports and exports:

Quarantine Act - Animal and plant quarantine with imports.

Export Control Act - Exports of canned and frozen fruits, dairy produce, eggs, dried fruit, fresh fruit, fresh vegetables, fish, grain, meat and honey.

Because of the resources and expertise at State level, the inspections for animal and plant quarantine and exports of grain, fresh fruit and vegetables are vested in State Departments of Agriculture. In N.S.W. the force undertaking these duties are agricultural inspectors.

INTRODUCTION TO AGRICULTURAL QUARANTINE

Agricultural quarantine is administered by Government to protect all facets of agriculture and the environment from unwanted pests and diseases of animals and plants. This is achieved by controlling the entry into Australia of animals and plants; animal or plant products; soil; cultures of living organisms; packing material and commodities; and the conveyance of goods.

The use of Government authority to enforce agricultural quarantine is based on the premise - it is economically preferable to undergo some inconvenience and expense in an effort to exclude a pest or disease rather than submit to the expense of controlling it indefinitely.

Background to Quarantine

Quarantine is derived from the latin word "Quarantum" meaning 40. It originally arose from the detention of ships and the isolation of passengers and crew when arriving from countries subject to epidemic diseases, such as bubonic plague, cholera and yellow fever. The 40 days had a traditional rather than a factual background.

The first quarantine is believed to have been imposed in Venice in 1376 when travellers suspected of being infected with bubonic plague were banned. It was not until 1850 that an international quarantine code relating to ships and commerce was drawn up at a convention in Paris.

While quarantine was first imposed for epidemic human diseases, the accent today is on animal and plant quarantine. In 1980 the World Health Organisation claimed the elimination of smallpox from the world and most countries have eliminated their quarantine surveillance of people arriving by sea and air. Australia has maintained a monitoring exercise for the occurrence of human diseases, such as cholera and malaria, but these are not quarantinable.

History of Agricultural Quarantine in Australia

As early as 1866 the colony of New South Wales passed an Act governing the importation of sheep and in 1871 for cattle. In Sydney, port inspection of plant material began in 1889 when the Export and Import Branch was established. The administrative office was in the old Mining Museum in George St. North, the fumigation chambers in Washington Lane near Day St. and seed was inspected at the Art Gallery in the Domain. The Commonwealth Constitution gave the Federal Government the full responsibility for human, animal and plant quarantine. Following Federation in 1901 the Quarantine Act was passed in 1908.

This shows that Australia was taking active agricultural quarantine measures as early as any other country. The first plant quarantine legislation was enacted by Indonesia when under Dutch control in 1877 to prevent the spread of coffee rust from Sri Lanka.

The Importance of Agricultural Quarantine

Those who expound theories of natural selection and survival of the fittest would suggest we let nature take its course and we do away with agricultural quarantine. This attitude could be disastrous for Australia because this continent was isolated from the rest of the world for eons of time and developed a unique flora and fauna.

Most countries have some native and unique species of plants, animals and birds. In Australia, most people are familiar with the more obvious of our species such as gum trees, kangaroos and kookaburras. But not all of a country's unique plant and animal life is quite so obvious. Each country, or region, has a collection of insects, fungi, bacteria, viruses, nematodes, snails and weeds that originated there. When man moves plants, seeds or goods from country to country he may transfer an insect pest or plant disease from its native habitat to a new location. No one can predict how the "immigrant" will behave in its new environment. But, freed from its natural enemies and competitors, and in contact with a possibly more susceptible host, it may be a more serious pest than in its native situation.

Man probably distributed more pests and diseases throughout the world during the last century than in any previous time in history. Many insects and diseases did not survive the long sea voyages of earlier days but too many did establish themselves in new countries. The large volume of cargo conveyed by fast transportation today has increased the risks for agricultural quarantine.

European Settlement in Australia

At the time of European settlement Australia had no commercial species of plants. The early settlers brought some plant pests and diseases, new to Australia, along with the crop species transported as plants or seeds.

Australia now has one of the most productive, richest and diverse agricultural systems in the world based on introduced crop species. Although one might expect that Australian food and fibre crops should, by now, be afflicted with every significant pest and disease, such is not the case. There is little doubt that Australia's geographic isolation and the long sea voyages undertaken by the early settlers eliminated a number of crop pests and diseases. Perhaps the unusually extremes of the Australian climate did not favour the foreign pests because no one can predict how an introduced plant pest or disease will perform in a new environment. It may have been simply chance. However, the fact is that while Australia does have diseases and pests of commercial crops, most of them introduced, there is still a large number of significant plant diseases and pests of agricultural, forestry and horticultural crops not established in Australia. More importantly, new crops for Australia invariably are free of major pests and disease except for those that move across from existing plant species - either introduced or indigenous.

All commercial livestock used in Australia's primary production have been introduced at some time or other. Few countries are as free of animal diseases and pests as Australia.

The assessing or risk for animal quarantine is very complex. In addition to the number of livestock diseases which threaten Australia, it is necessary to consider the numerous avenues for possible entry. The most obvious means of introduction include infected animals or animal products such as meat. Goods such as farming equipment, animal containers, food containers, stockfeed, hay, straw packing may be carriers of animal diseases. Then there is the difficulty of detection. For example, the sheep disease, Scrapie, has an incubation period which can exceed four years. Rabies may incubate for nine months. Other diseases may be harboured in animal or plant products for extended periods such as Newcastle disease in frozen poultry for ten months; swine fever in frozen pork for several years and foot and mouth disease virus on hay for periods up to fifteen weeks. Other carriers of animal diseases include animal excreta, semen, eggs.

In respect of animals, the Australian native species such as the marsupials are not expected to be likely reservoirs for introduced exotic diseases such as foot and mouth or Bluetongue. However, a very significant problem could arise from feral animals such as pigs, horses, buffaloes, goats, donkeys, camels, if unfortunately a serious exotic animal disease should happen to reach Australia. Foxes, feral cats, feral pigs and dingoes could become a reservoir of infection for Rabies. Wild pigs are already under suspicion as carriers of a kind of tuberculosis that infects cattle.

COMPONENTS OF QUARANTINE ACTIVITY

There are several quarantine systems which are used separately or collectively to prevent the introduction and establishment of new pests and diseases. The use of a complete embargo or prohibition on a risk product presents many problems as few countries are self-sufficient and new genetic material is necessary to progress. Also, an embargo is likely to be more restrictive on a scientifically developed country which has recorded specific diseases or pests. The risks could be greater from countries with less technological development. While prohibitions must be maintained for high risk areas, the use of controlled introductions involving inspection on arrival, prescribed treatment and post-entry quarantine generally provides the quarantine safeguards.

Inspection at point of entry is the first line of defence but has physical limitations. It is impossible to detect some stages of insects and diseases by inspection. Therefore quarantine prohibits the host material from infected areas considered a high quarantine risk. In this situation, inspection is limited to search and seizure of the host material. Despite the deficiencies, there is no alternative but to depend on inspection when volume is high and risk is low, e.g. with timber and seeds not specifically restricted. Controlled introductions of prohibited products are permitted when quarantine risks can be overcome. For instance, a fruit may receive a fumigation treatment to eliminate possible introduction of insects, such as an exotic fruit fly. Seed introduced for purposes other than sowing may be rendered non-viable via treatment to eliminate the risk of a seed-borne disease being established.

Inspection and certification at the point of origin with the provision of a phytosanitary certificate for filling obligations under FAO-IPPC for freedom from pest and disease and for a prescribed treatment provides an acceptable quarantine safeguard.

QUARANTINE TREATMENTS

Treatments are generally selected to give the degree of quarantine security desired with least risk to the product. However, when there is no alternative, a treatment to give quarantine security may cause injury. This can be so with a fumigant, such as methyl bromide.

The range of treatments commonly used in quarantine at present include:

1) Fumigants - methyl bromide, ethylene dibromide, ethylene oxide, phosphine.
2) Pesticides, fungicides, bactericides, herbicides and sterilants.
3) Heat
4) Hot water
5) Cold sterilization
6) Ionising energy.

COMMON QUARANTINE USES

Live plants - 1, 2 and 4

Seed for sowing - 1, 2, 3 and 4

Seed for devitalizing - 1, 3 and 4

Fresh fruit and vegetables - 1 and 5

Timber - 1 and 3

Contaminants (seed, soil and insects) - 1, 2 and 3

Bales of used sacks - 6.

FUTURE OF IONIZING ENERGY WITH QUARANTINE

Ionizing energy would appear to have an excellent future as a quarantine treatment. Its acceptance internationally as a quarantine treatment over the range of products discussed at this workshop will relate to public acceptance generally. While we lack experience in the use of irradiation for quarantine purposes, it would appear to be a good tool particularly for some commodities and in particular foodstuffs, including fresh fruit and vegetables. The use of irradiaiton in the export of foodstuffs will be entirely dependent on acceptance by the importing country.

At this stage the Australian Quarantine Service accepts the use of irradiation in principle, and on the demonstration of its efficacy by an exporting country it could be accepted for a range of uses:

- the elimination of insects
- the elimination of disease
- devitalization and treatment of seed
- treatment of soil.

The treatment and dosage would need to be verified by an authority of the exporting country and certified by a phytosanitary certificate. This acceptance of irradiation by Australian Quarantine will be dependent upon our National Health and Medical Research Council setting up tolerance for particular foodstuffs. It would be necessary for research to determine if such dosages have any deleterious effect on the quality of the product as this will not be a major concern of quarantine. It is not expected that irradiation would replace fumigants as a major quarantine tool where no restriction is imposed on that usage, e.g., with products not intended for human consumption, such as timber. Fumigation is a very flexible procedure and is most suitable for large quantities of product. At this stage it would seem that irradiation will have most use with valuable goods of lesser volume and foodstuffs, including fruit and vegetables which may carry pest or disease of quarantine concern.

QUARANTINE INSPECTIONS

Agricultural Quarantine

Animals and animal products
e.g. cats and dogs ex New Zealand, cheese, tinned meats, hides, milk products, fishmeal, etc.

Plants and plant products
e.g. live plants, seeds, spices, edible nuts, cut flowers, fresh fruit and vegetables, dried fruit and vegetables, etc.

Other goods
Timber, timber packaging, secondhand agricultural machinery, motor vehicles, scrap metal, secondhand tyres, etc.

Key Locations in N.S.W.

Ports of Sydney, Newcastle and Wollongong

Airports of Sydney, Richmond and Williamtown.

Operational Areas

1. International terminals - Passengers and air crew baggage clearance, commercial aircraft, airforce and sea passengers.

2. Bond stores - Clearance of air and sea cargo.

3. Container terminals - The examination externally of containers for soil contamination and snails and inspection of cargo for infested, prohibited or contaminated goods.

4. Waterfront - Inspection of agricultural machinery and other cargo not containerised, examination of overseas yachts for prohibited foodstuffs and ships pets.

5. Mail exchange - Examination of parcels and packets from overseas for restricted, prohibited and infested foods of animal and plant quarantine interest.

6. Timber - Inspection for insect infestation and contamination with soil. Main countries of supply - North America, Malaysia, Philippines and New Zealand.

7. Approved premises which are private premises registered to perform various functions - processors of restricted imports, treatment areas, laboratories and examination areas.

8. Nursery stock - specialized staff
   Inspection and treatment of approved imports of live plants, subject to imports being grown in registered quarantine glasshouses for specified period.

9. Tropical fish - specialized staff
   Inspection and identification of approved imports, then post-entry quarantine under supervision for specified period.

EXPORT OF PRIMARY PRODUCE

The Export Control Act provides for the control over the export of primary products and the legislative backing for the administrative and technical requirements for export inspection.

Under the controls of Regulations or Orders, the export of specified goods are prohibited or restricted to certain places and conditions. These include the registration of premises to meet the necessary standards of construction, security, hygiene, lighting, sound, equipment and facilities for inspection. These may further control the granting of licences or permission to export. Notice must be given to an authorized person of the intention to export such goods.

An authorized officer has powers for entry, search, inspection and seizure in registered premises and to seek a warrant for the same powers in unregistered premises. If requested, it is an offence if the owner refuses to assist the officer in his duties.

Trade description is an important part of the Export Control Act. The contravention of the Regulations pertaining to a trade description or the use of a false trade description makes offenders liable to severe penalties. Trade description means any description, statement or pictorial representation of the nature, quality, quantity or grade of the goods; the origin exporter, etc. and includes any label indicating the above matters.

The majority of export inspection work by agricultural inspectors is undertaken in Sydney for fresh fruit and vegetables, nursery stock, grain and field crops. A large group of inspectors also inspects export grain and field crops at the Newcastle Terminal. Country based inspectors can be called upon to inspect fruit and vegetables being containerized at country centres. They are also being increasingly involved in the inspection of other field crops, e.g. rice and cotton, where importing countries require an international phytosanitary certificate (health certificate) for apparent freedom from pest and disease. Inspectors are required to determine that goods submitted for export meet the requirements set by Regulation or Order for export and that any specific requirements of the importing countries are met before completing the phytosanitary certificate and export permit.

Inspectors at grain terminals also inspect the terminals for hygiene and freedom from insects, and direct cleaning procedures and treatments where necessary. Also, they survey ships for freedom from insects and infestable residues and direct treatments where necessary before giving permission to load.

INTERNATIONAL PLANT PROTECTION CONVENTION (IPPC)

Australia is a member of IPPC which operates within the Food and Agricultural Organisation (FAO) of the United Nations.

The contracting parties recognise the usefulness of international co-operation in controlling pests of plants and plant products and in preventing their spread and especially their introduction across national boundaries and, desiring to ensure close co-ordination of measures directed to these ends, have agreed as follows:-

(1) With the purpose of securing common and effective action to prevent the spread and introduction of pests of plants and plant products and to promote measures for their control, the contracting parties undertook to adopt the legislative, technical and administrative measures specified in

this convention and in supplementary agreements pursuant to Article III.

(2) Each contracting party shall assume responsibility for the fulfilment within its territories of all requirements under this convention.

As a member of IPPC we are bound by the rules and it is important when we issue Phytosanitary Certificates that these be correct and meet the requirements of the importing country.

EXPORT INSPECTION - FRESH FRUIT AND VEGETABLES

Reason for Inspection

1) For compliance with export standards involving:

   Pest and disease
   Maturity
   Soundness
   Grade standards
   Minimum sizes
   Fungicide treatments
   Pre-cooling
   Packaging
   Product ability to out-turn satisfactorily.

2) Phytosanitary certification as required by importing countries:

   Fruit fly disinfestation by
   - EDB fumigation
   - Cold sterilization

   Area freedom - 80km/12 mths for Queensland Fruit Fly - New Zealand

   Area freedom - Onion smut - New Caledonia

   Area freedom - Cattle tick - Fiji

   Endorsement re San Jose scale - Germany

   Special inspection/treatment - Light brown apple moth - Canada.

Place of Inspection

Exporters premises at Flemington Markets

At orchard/packing shed

At cold stores

At shipside.

Method of Inspection

Aim to inspect 10% of total consignment in a detailed systematic manner.

Suitable equipment - knife, magnifying glass, size rings, weighing scales, maturity testing equipment, good light, work bench.

On completion, leave product in condition similar to that at start of inspection.

Supervision of Loading

Air cargo - Suitably stowed to avoid damage

Containerised sea cargo
- Dunnaging
- Free air flow
- Head space of 50mm.

Documentation

Notice of intention to export/the export permit
- Need for accurate detail

- Need for advance notice of intention to ship
- Distribution of copies.

Phytosanitary certificates
- Various types
- Accuracy of detail
- No erasures/alterations
- International Plant Protection Convention rules
- Number of copies/distribution.

Out-turn Inspection

Role of Australian Horticultural Officer, Singapore and London.

IMPORTANT PESTS - IMPORT AND EXPORT INSPECTION

Some important pests which are of concern and the methods of treatment are:

Quarantine - Exotic pests

Khapra Beetle - The most serious stored product insect in the world. Not recorded in Australia. Infestations are treated by fumigation with methyl bromide at 80g/m^3 for 48 hours at 21°C.

Giant African Snail - A serious pest of horticultural and agricultural crops. Not recorded in Australia. Infestations treated by fumigation with methyl bromide at 128g/m^3 for 24 hours at 21°C.

Carpenter Ant - A wood damaging ant that can cause structural damage to timber in service. Not recorded in Australia. Infestations treated by fumigation with methyl bromide at 48g/m^3 for 24 hours at 21°C.

Other Pests of Concern - West Indian Drywood Termite, Oriental Fruit Fly and other exotic fruit flies, timber pests (Bostrychid, Cerambycid, Scolytid beetles and Wood Wasps), exotic aphids, thrips and mites. A variety of treatments may be used to control these pests including methyl bromide, ethylene oxide, ethylene dibromide and heat treatment.

Exports - Pests which occur in Australia

Queensland Fruit Fly - Some countries accept area freedom certificates (i.e. produced 80 km from known occurrence), whereas other countries require treatment with EDB or cold sterilization.

San Jose Scale - Fruit is inspected for freedom from scale prior to export. Treatments are applied if requested by importing country.

Codling Moth - Fruit inspected prior to export. Treatments applied if requested by importing country.

As well as inspection of fruit and vegetables, an important role in export inspection is the inspection and certification of grain and various plant products. This involves the inspection of grain and plant products at export, as well as the inspection prior to loading of the vessels and/or containers carrying these cargoes.

A nil tolerance for live insects is enforced for grain exports. Some of the insects which are of concern in export grain and plant products are lesser grain borer, rust red flour beetle, saw-toothed grain beetle, rice weevil and tropical warehouse moth.

Treatments for these insects detected during loading of grain or plant products, or during inspection of vessels or containers are spraying with insecticides or fumigation.

LECTURE 13

POST-HARVEST STORAGE & PROBLEMS

D. EVANS

AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

POST-HARVEST STORAGE AND PROBLEMS

D.E. Evans
CSIRO Division of Entomology
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INTRODUCTION

This paper seeks to provide a conceptual framework and data base for the consideration of storage losses and the logical evaluation of irradiation and other methods of loss prevention.

Loss during storage can be either quantitative, i.e. decreased mass, or qualitative, e.g. changed appearance or lowered nutritional value (Howe, 1965a). However, with the introduction of more stringent marketing criteria, economic loss is increasingly correlated with the presence of small numbers of live insects and contaminants such as insect fragments, pesticides and mycotoxins in an essentially sound commodity. The principal causes of loss are the metabolism of the commodity itself, and attack by microflora, insects, mites, and, to a lesser degree, rodents and birds.

The sound management of the factors responsible for loss during storage rests on principles that are applicable whenever and wherever cereals, pulses, nuts, dried fruits, spices, dried fish and their derivatives are stored. These general principles will be illustrated here in terms of the control of pests in bulk grain that must be sold essentially free of live insects, i.e. must meet a "nil tolerance", on an international market where the admixture of residual insecticides with grain is becoming less acceptable.

THE PRODUCTION SYSTEM CONCEPT

In considering the prevention of storage losses, it is useful to think of a storage as an ecosystem (Sinha, 1973; Calderon, 1981) and to identify those components of the system that influence deterioration. However, storage is only part of a system comprising production, harvesting, handling, storage, transportation, marketing and processing. Accordingly, the term "production system" (Geier, 1982a) is used here, rather than "ecosystem", to stress, firstly, the artificiality of the so-called storage ecosystem and, secondly, the unusual opportunity that exists to manipulate the system to the benefit of the commodity. Within this conceptual framework, the prevention of loss involves the methodical consideration and management of the outputs, inputs and constraints of pest control as a sub-system of a much larger production system.

OUTPUTS OF THE PRODUCTION SYSTEM

The desired outputs, or objectives, of the production system are to provide sound grain that is free of pests, diseases and contaminants, such as weed seeds, mycotoxins and excessive pesticide residues. Such outputs are specified in contracts between the seller and the buyer and may be reinforced by national legislation, such as Australia's Exports (Grain) Regulations, and by international phytosanitary certificates (Evans, 1982).

INPUTS TO THE PRODUCTION SYSTEM

The inputs to a production system comprise biotic and abiotic components and control and operational practices such as hygiene, inspection and sampling, and irradiation. The most important components of the system are:

Biotic

The grain

Weed seeds, chaff, straw and grain fragments

Bacteria, moulds, and yeasts

Insects and mites

Rodents and birds

Abiotic

The storage structure and associated handling and transport facilities

Temperature

Moisture

The intergranular atmosphere

Contaminants such as soil and insecticides

Such components are mostly interdependent. This is particularly true of the condition of the grain itself and the organisms that exploit it. This relationship is so strong that no soundly based system of pest management can ignore the factors that influence the keeping quality of the commodity itself.

BIOTIC INPUTS AND THEIR MANIPULATION

The Grain and Associated Matter

The grain is a living, but resting, organism whose viability and metabolic activities, particularly respiration and germination, may be profoundly influenced by the storage environment (Roberts, 1972). Keeping metabolism at a low level by holding grain moisture and temperature at low levels is essential to preserving the quality and germinability of the grain and to minimising the likelihood of the grain being exploited by pests.

The consequences of respiration are loss in mass and the production of heat, carbon dioxide, and water or, in the absence of oxygen, ethyl alcohol. More subtle changes during storage may involve an increase in free fatty acid levels and the breakdown of proteins, carbohydrates, and vitamins (Pomeranz, 1982). The maintenance of alpha-amylase and protein levels is of major importance in cereals destined for dough and breadmaking, as is the preservation of germinability in grain for malting and for seed. Under very poor storage conditions, the grain may germinate and become unsuitable for human consumption.

Grain that is damaged during harvesting and pre-storage handling is susceptible to enzyme-mediated chemical change and to attack by insects and microflora (Wallace and Sinha, 1962). Similarly, the presence of weed seeds, chaff and straw renders otherwise sound grain more likely to be infested by insects (McGregor, 1964) and susceptible to fungal attack (Burrell, 1982). Much progress has been made in the development of insect-resistant varieties of maize and cowpea but there are few examples of effective breeding programs for resistance in other cereals (Horber, 1984).

Clearly, the implication of the above is that grain should be stored in a sound, clean, dry and preferably cool condition. This may involve the choice of appropriate harvesting equipment to minimize physical damage to the grain and the provision of cleaning and drying facilities as part of the pre-storage system.

Insects and Mites

Over 100 species of insects and mites may be found in stored products but only about 20 of them (Table 1) are commercially important.

The nature of loss and damage

Losses caused by insects and mites may be manifested directly through consumption of the endosperm, death of the embryo, and contamination with live insects, insect fragments, excreta and chemical secretions (Howe, 1965a). Indirect manifestations range from 'dry grain' heating, through moisture migration, to sprouting. Dry grain heating is caused by insects respiring within the grain mass: it may be localised as 'hot spots' (Howe, 1962), or general, where temperature gradients and convection currents are established. Convection leads to the transfer of moisture from warm parts of the mass to cool parts, such as the surface, where temperatures may be at or below dew point and water deposited that enables the grain to sprout. Mites may be responsible for allergic reactions in persons handling grain and for poor weight gains in grain-fed stock (Wilkin and Thind, 1984).

Biology and ecology

Each species has a characteristic range of limiting and optimal temperatures and humidities (Table 1) (Evans, in press). Broadly speaking, development is possible within the range of 10-40°C and optimal within 25-35°C. Relative humidities of 65-80% are usually optimal but *Tribolium castaneum* and *Trogoderma granarium*, for example, can complete development in flour at humidities as low as 1-2%. Mites may develop below 10°C but are inhibited by humidities $<$ ca 65% (Cunnington, 1976; Sinha, 1973). Finite 4-weekly rates of increase range from 4 in *Ptinus tectus* to 2,500 in *Acarus siro* (Howe, 1965b).

Some species attack whole grains while others feed on floury fragments generated by whole-grain feeders. Still others are scavengers that feed on moulds, accidentals that are harvested with the grain but die during storage, and predators and parasites of the grain feeding species.

Biological control

The possibility of using the natural enemies of the insects and mites of stored grain as biological control agents has often been considered (Evans, in press). Apart from *Bacillus thuringiensis* and viruses, which can be applied as biological insecticides for the control of moths, it appears that the use of readily visible natural enemies is suited only to situations where nil tolerance does not apply, for example, in locally used commodities that are cleaned before use, animal foodstuffs and seed grain.

Currently, pheromones appear to have more promise as aids to sampling than they do as a means of disrupting mating behaviour (Hodges, 1984).

Microflora

The microflora of grain comprise mainly bacteria, fungi and yeasts. Bacteria and 'field' fungi such as species of *Altenaria*, *Cladosporium*, *Fusarium* and *Helminthosporium* predominate in ripening and newly harvested grain (Lacey *et al*., 1980). During storage, bacteria usually decline and field fungi are replaced by species of *Aspergillus* and *Penicillium* (Wallace, 1973; Christensen and Sauer, 1982).

Fungi are important because they consume the grain and are the major cause of 'wet grain' heating and associated problems of moisture transfer and sprouting. In addition, they may discolour the grain, produce musty odours and lower germinability (Wallace *et al*., 1983).

The toxins produced by the secondary metabolism of species of *Aspergillus*, *Fusarium* and *Penicillium*, for example, are harmful both to man and domestic animals in that they may be carcinogens, cause hepatitis and other conditions (Lacey *et al*., 1980, Mirocha and Christensen, 1982). Excessive levels of mycotoxins may lead to grain being rejected. Fungal spores can be responsible for allergic conditions such as "farmer's lung" (Lacey *et al*., 1980).

Microflora, particularly fungi, seldom develop at relative humidities $<$ ca 65% (Lacey *et al*., 1980), and storing grain in a dry condition is therefore the most appropriate method of control.

Rodents and Birds

Mus musculus (the house mouse), *Rattus norvegicus* (the Norway rat) and *Rattus rattus* (the roof rat) are commonly associated with stored products. Although they consume grain, the economic importance of rodents in bulk grain rests largely on the contamination of the grain and its by-products with their carcasses, hair, faeces and urine.

Control depends on hygiene, physical exclusion, i.e., 'proofing' (Jenson, 1979), trapping, and baiting with rodenticides (Greaves, 1982; Harris and Bauer, 1982).

Colomba livia (the pigeon), *Streptopelia decaocto* (the collared dove), *Sturnus vulgaris* (the starling) and *Passer domesticus* (the sparrow) are common around granaries. Their economic importance is largely related to the contamination of grain with carcasses, feathers and faeces. Their nests and faeces provide harborage and breeding sites for insects and mites. Control again rests on hygiene, exclusion, trapping, and baiting (Tyler, 1979; Hunter, 1980).

ABIOTIC INPUTS AND THEIR MANIPULATION

The Storage and Associated Handling Equipment

In simple terms, the purpose of a storage is to protect harvested grain from damage by the weather, attack by pests and microflora, and to prevent it being stolen. However, the design of a storage influences grain moisture and temperature, the intergranular atmosphere, and the rate at which pests may enter or leave the system. Above all, the design of a storage system and associated facilities determines the ease with which hygiene, inspection and pest control can be achieved.

Keeping the grain dry and cool is crucial (Evans, in press). The siting, orientation and construction of the storage are important in this regard.

The inner surfaces of the storage should be free of cracks likely to provide harbourage for pests. Similarly, the use within the storage of beams and pillars that form ledges where grain and dust can rest should be kept to a minimum. Structures that are gravity-emptying and, hence, largely self-cleaning are to be preferred. Provision of access for cleaning and inspection should be an integral part of the storage design. Similar criteria also apply to the design of combine harvesters and grain vehicles.

The proofing of storages against the entry of rodents and birds has been mentioned earlier. The sealing needed for the effective use of modified atmospheres (see below) provides physical exclusion of insects (Banks and Ripp, 1984).

Temperature

Temperature is a major driving force in the storage environment, influencing directly or indirectly the moisture content of the grain and its interstitial atmosphere, the metabolism of the grain, invertebrate pests and microflora, and the efficacy of insecticides, modified atmospheres, and irradiation.

Low temperatures

Low temperatures are advantageous in that they lower the metabolism of the stored cereal, restrict the population growth rate of insects and mites and inhibit the development of microflora. In addition, cool conditions slow the breakdown of insecticides. However, most pesticides, modified atmospheres, and irradiation are less effective in cool grain than they are in warm grain.

Cooling by forced ventilation with either ambient or chilled air (Foster and Tuite, 1982; Evans, in press) is widely accepted as an effective way of suppressing insects and, to a lesser extent, of preventing the increase of mites and the growth of microflora. Further benefits of cooling are that aeration usually minimizes heating and temperature gradients and prevents mustiness.

For insect control, the aim of aeration is usually to reduce grain temperatures to 15-17°C (Burges and Burrell, 1964) at which level most species either cannot complete development (Table 1) or can increase only very slowly (Howe, 1965b; Evans, 1977). To suppress mites (Cunnington, 1976) and fungi (Burrell, 1982) temperatures of less than 5°C may be needed.

Cooling may not always be effective in disinfesting grain, i.e., in achieving nil tolerance standards. Much depends on the intrinsic cold-tolerance of the species and developmental stages present (Solomon and Adamson, 1955), the rate of cooling, the temperature attained and the time for which it prevails (Evans, in press).

Aeration may provide little protection from damage or re-infestation once the grain is removed from storage, and can lead to changed moisture levels (Ghaly, 1984).

High temperatures

Infrared, radiofrequency, and microwave heating (Kirkpatrick, 1974) are effective in disinfesting grain but, currently, would be difficult to scale-up to the throughputs needed at either export or import terminals. However, rapid heating in a stream of hot air in a pneumatic conveyor (Dzhorogyan, 1957), fluid bed (Evans *et al.*, 1984) or spouted bed (Claflin, *et al.*, 1984) can be readily scaled up (Liborius, 1984). In Australia, wheat has been disinfested in a pilot-scale fluid bed system at rates as high as 200 t h^{-1} without the grain being either dried appreciably or damaged.

Moisture

Moisture has both direct and indirect influence on many of the components of the production system. The relationship of the moisture content of the grain to that of the intergranular atmosphere and to temperature is complex (Pixton, 1982).

Low humidities or moisture contents, say $<$ 65% R.H. or $<$ 14% m.c., are generally preferred because they minimise the metabolism of the grain and inhibit the development of mites and fungi. However, aridity usually has less influence on insects than it does on mites and fungi.

Low moisture contents may be attained either passively, as in Australia where wheat commonly has a moisture content of 11% or less when harvested, or actively, by artificial drying with either ambient or heated air (Evans, in press). The average grain temperatures provided by most grain dryers are not high enough to kill insects within the grain. The influence of drying is nevertheless valuable because pests such as Sitophilus (Birch, 1953), cannot oviposit in grain of $<$ ca 9% m.c. and the developmental periods of their immature stages are prolonged at low humidities and their survival is decreased.

The Intergranular Atmosphere

The building or modification of storages to high standards of gastightness (Banks and Annis, 1980; Banks, 1984b) has made the modification of the intergranular atmosphere a powerful means of pest control regardless of whether the modification involves so-called controlled atmospheres (see below) or conventional fumigants. Controlled atmospheres, in particular, offer operational flexibility in that they can be used either as 'one-shot' fumigants, or as long-term residue-free protectants, when the atmosphere is maintained.

The effective use of modified atmospheres is demanding in that an appreciation is required of the standard of gastightness needed, the physico-chemical processes involved and the influence of meteorological conditions on the atmosphere and commodity within the storage (Banks, 1984a,d; Banks and Annis, 1984). Potential constraints to the use of modified atmospheres are high mammalian toxicity, moisture migration and denial of access for inspection and handling (Banks and Ripp, 1984).

Controlled atmospheres

Controlled atmosphere (CA) storage involves changing the concentration of gases within a storage to give a lethal atmosphere. It is a means of disinfesting both the grain and the fabric of the storage. In addition, it may inhibit the development of microflora, and preserve the quality of the grain.

Either oxygen-deficient atmospheres ($< 2\%$ O_2, usually generated by purging with N_2) or carbon dioxide-enriched atmospheres ($> 60\%$ CO_2, made by adding CO_2) may be used, although the latter are currently more practicable (Banks *et al.*, 1980). Neither atmosphere leaves residues within the grain. Currently, CA are mostly generated from liquefied gases but other means exist (Banks, 1984e). In Australia, an initial level of ca 70% CO_2 followed by $>$ 35% for at least 10 days is the preferred treatment (Banks, 1979).

In terms of maintaining quality, the CA storage of dry cereals confers only minor benefits over storage in normal atmospheres. However, the CA storage of commodities in equilibrium with air at relative humidities of 60-75%, may be beneficial in that germinability, low fatty acid levels, low mycotoxin levels and freedom from taint are maintained to varied extents (Banks, 1981).

The controlled atmosphere must be created as soon as possible after the grain is in-loaded. With grain of 12-16% m.c., particularly where moisture migration is likely, it may be advisable to maintain the atmosphere throughout storage and to process the grain as soon as it is out-loaded. Tainting and fermentation are likely to occur when grain of 16% m.c. or greater is stored (Hyde and Burrell, 1982).

Hermetic storage

Hermetic storage involves the modification of the intergranular atmosphere through the respiration of the grain and associated pests and micro-flora (Nash, 1978; Hyde and Burrell, 1982; Shejbal and Boislambert, 1982; Banks, 1984c; Navarro *et al.*, 1984).

The atmosphere achieved depends on the temperature and moisture content of the grain, the initial abundance of pests and micro-flora, and the storage period. The level of control attained varies from complete kill to suppression of population increase.

Fumigation

When used properly, fumigants disinfest both the grain and the fabric of the storage and, in practical terms, are removed from the commodity when treatment is followed by ventilation. They are toxic to both invertebrates and vertebrates, and may be phytotoxic. They may also damage metals and the fabric of the storage.

Increasingly, only methyl bromide and phosphine are widely used because of concern over health and safety (Monro, 1969; Bond, 1984).

Methyl bromide (CH_3Br) is applied as a liquefied gas, frequently with the aid of a vaporizer and a distribution and recirculation system.

Phosphine (PH_3) is liberated, in the presence of water vapour, from either tablets, pellets or plates of aluminium phosphide or magnesium phosphide. These formulations may be admixed with the grain as it is put into a bin, probed into the grain from the surface of the bulk, or applied as a surface treatment in removeable trays or paper 'blankets' (Monro, 1969; Banks and Sticka, 1981; Anon., 1984; Banks, 1984d; Friemel, 1984). Phosphine is inflammable and explosive and must be used with care (Anon., 1984; Cook, 1984; Green *et al.*, 1984).

Successful fumigation depends on achieving an appropriate concentration of the toxicant throughout the grain bulk for a sufficient time. Choice of fumigant and definition of the dosage required rests heavily on a knowledge of the most susceptible stage to be controlled and its biology besides information on the speed of action of the fumigant, the time available for treatment, temperature, degree of gastightness etc.

Dosage rates are given in Anon. (1984). For cereals, they range from 25 g m^{-3} at 20°C to 50 g m^{-3} at 10°C for a 24 h exposure. Equivalent exposures to 1 g m^{-3} of phosphine range from 12 days over 20-30°C to 16 days over 10-20°C (see also Winks *et al.*, 1980).

Treatment must be followed by either passive or active ventilation to lower the concentration of toxicant in the workspace and to reduce levels within the grain: particular care must be taken with methyl bromide, which is more strongly sorbed than phosphine (Monro, 1969). Ventilation periods of from 12-24 h with active ventilation to 5-7 days with passive ventilation may be needed.

Insecticides

Insecticides applied to the fabric of the storage, to the head space, or to the stored grain itself offer a remarkably robust and reasonably priced method of control. They constitute the only method that in one operation has the potential to disinfest the grain on receival, and also protect it in storage and during transportation to the consumer. Furthermore, they are easy to use, not demanding of storage design, and do not require expensive application equipment. However, changed societal attitudes to the admixture of insecticides with foodstuffs and the development of resistant strains of insect pest are major constraints to their continued use.

The use of insecticides in grain storages and on grain is strictly regulated. Of particular importance in export grain are the maximum residue levels set by WHO/FAO Codex Committee on Pesticide Residues and the Codex Alimentarius Committee (Snelson, 1984).

Some commonly used insecticides are listed in Table 2. They may be used as:

1. Knockdown sprays (KS), particularly against flying insects or insects hidden in cracks and crevices.

2. Surface sprays (SS) applied to the surface of bulk grain or bag stacks.

3. Structural treatments (ST) applied to the fabric of the storage.

4. Grain protectants (GP) admixed with the grain, and

5. Grain treatments (GT) that are added to the grain to kill existing infestations quickly without leaving unacceptable residues at the time of shipping.

The chemical used will depend on the species detected and whether or not resistant strains are present. At times it may be necessary to use a mixture of insecticides. In Australia, for example, when organophosphorous resistant *Rhyzopertha dominica* are present with other species, synergized bioresmethrin and fenitrothion are used. Both underdosing and, hence, possible selection for resistance, or over-dosing and excessive residue levels must be avoided.

Irradiation

The evaluation of irradiation as a means of pest control has been proceeding for some 30 years. The extensive entomological literature on the subject has been reviewed by Tilton and Brower (1973), Tilton (1975, 1979), Lorenz (1975), Watters (1979), Tilton and Burditt (1983) Shipp (1983) and Brower (1984).

Accelerated electrons are generally preferred for the treatment of bulk grain (Cornwell and Bull, 1960; Cornwell, 1966). An accelerator has been established in the USSR for the disinfestation of imported grain (Zakladnoi et al., 1981). It has a nominal throughput of 400 t h^{-1} and provides a dosage of ca 0.25 k Gray at 1.4 MeV. Insects are instantly sterilized by this dosage but, depending on species, developmental stage and grain temperature, may take as long as 6 weeks to die (Watters, 1979, VNIIZ, unpublished data).

OPERATIONAL PRACTICES

In addition to the manipulation of biotic and abiotic inputs, several operational practices and legislative requirements play a major role in preventing loss during storage.

Hygiene and Stock Control

Good hygiene is as an essential foundation to all other methods of control. It minimizes the risk of sound commodities being invaded by pests migrating from residues in handling equipment and vehicles and from spillages in and around the storage. Hygiene standards must be monitored by regular inspection before, during and after storage, and reinforced by stock control that seeks to minimize the chance of cross-infestation (McFarlane and Morley 1970).

Inspection and Sampling

Inspection and sampling are crucial in the management of stored grain (Evans, in press). They provide information on the state of the commodity, quantitative and qualitative losses, the nature and extent of any infestations and, thereby, the need or otherwise for action. Grain should be inspected at least monthly and the findings recorded so that the history of a given grain mass can be compiled and the efficacy of any remedial action can be judged (McFarlane and Morley, 1970).

Quarantine

Plant quarantine regulations require that certain or all agricultural produce is inspected before entering a given country. This lessens the risk of exotic pests such as *Trogoderma granarium* and pesticide-resistant strains of already established pests becoming introduced. The regulations may also cover the safe disposal of grain residues removed following inspection of vessels carrying export grain (Morschel, 1981).

THE NEED FOR INTEGRATED PEST MANAGEMENT

The synthesis of effective management strategies for stored grain and its pests involves the combination, either concurrently or sequentially, of procedures and control measures within a production system that is sympathetic to the needs of quality and pest control (Evans, 1982; in press). This may involve combinations of:

pre-storage procedures;
storage design, hygiene and management;
cooling and drying;
cooling and insecticides;
sealed storage and non-residual control methods such as modified atmospheres, heat disinfestation, and irradiation.

CONSTRAINTS ON IPM

Constraints to the development and adoption of IPM strategies can be categorized as biological, technological and socio-economic (Geier, 1982c).

Biological constraints

Obvious constraints are:

1. The grain is a living organism that is sensitive, for instance, to damage by impact (Bailey, 1962), heating and drying (Nellist, 1980; Ghaly and van der Touw, (1982), fumigants (Munro, 1969), and irradiation (MacArthur and D'Appolonia, 1984). Accordingly, control measures must be chosen and used in a way that will not impair the keeping qualities, wholesomeness or functional properties of the grain.

2. Grain may be subjected simultaneously to the harmful influence of a complex of processes and organisms that may require several quality and pest management measures to be undertaken concurrently.

3. Resistance to insecticides and fumigants (Champ and Dyte, 1976; Tyler *et al.*, 1983) and, to a lesser extent, rodenticides (Hunter, 1980) is both frequent and widely distributed. Resistance to controlled atmospheres also appears possible (Bond and Buckland, 1979; Dias and Navarro, 1983).

Technological constraints

Several general issues can be identified.

1. Only certain insecticides, modified atmospheres, heating and irradiation can, for certain, *disinfest* grain and

hence achieve nil tolerance at the time of export. Even so, some modified atmospheres (e.g. N_2 atmospheres at low temperatures) and irradiation may have to be used several weeks before export to ensure that the grain is insect-free.

2. The alternatives to insecticides provide little or no residual protection, where desired, after outloading.

3. Techniques such as cooling and drying with ambient air depend greatly on climate.

4. Some procedures are apparently antagonistic. For example, cooling diminishes the efficacy of certain modified atmospheres and the sealing required for modified atmospheres makes inspection and sampling difficult.

5. Modified atmospheres and, to a lesser degree, the combination of non-residual techniques (heat disinfestation and irradiation) with physical exclusion demand a high standard of storage design and fabrication.

6. Some of the newer methods may impose operational challenges such as increased risks to operator and plant, longer residence time to ensure efficacy, and the need for rational sequencing and forward planning.

Socio-economic Constraints

The parties involved in pest control are the agent of pest control, the producer, the consumer and the 'fourth party', i.e. the environmentalist and the government (Geier, 1982d). Social and economic factors impinge on the interests of all four parties and, hence, are likely to influence the adoption or otherwise of new pest management systems.

Social factors

Increased complexity and sophistication may hinder the adoption of new techniques by people used only to simple methods like insecticides. Lack of knowledge and insight may similarly militate against the establishment and use of a variety of pest control tactics in a strategically sound manner (Geier, 1982b). Such obstacles can be surmounted by training and extension programs.

Also important is concern over the high mammalian toxicity of fumigants and controlled atmospheres, explosions in heat-disinfestors, leakages from irradiators, and like matters. Once again, such fears must be overcome by educating those that use the new procedures and the community at large. In this context, it is necessary to recognise the growing role of environmentalists in alerting consumers to the hazards, real or supposed, of pest control and also the tendency of governments to respond to such activity by increased regulation.

Economic factors

The intangible nature of the economic loss caused by the finding of live insects in exported grain (Howe, 1965a; Evans, 1982) hinders the quantification of the benefits of pest control as a whole when both economic threshold and economic injury levels are set at zero. The immediate loss is merely the cost of treating or cleaning the infested cargo. In the longterm, however, freedom from insects is an important 'non-price' attribute on export markets and unsatisfactory out-turns must be kept to a level that does not evoke lowered prices and, particularly, reduced purchases. Due to the technical difficulty of quantifying damage (Boxall *et al.*, 1979), cost : benefit ratios may be obscure even when more tangible losses are incurred.

The cost of pest control has been considered at both tactical and strategic levels in Australia (Love, 1984; Johnston, 1981). Such economic studies highlight the need to consider pest control measures as part of a production system within which both capital and handling costs are important. Reducing dependence on insecticides almost invariably involves increased capital outlay and, unless a crisis prevails, compelling economic arguments are needed to initiate investment and change (Connell, 1975).

IRRADIATON: AN EVALUATION

Cornwell (1966) and Bailey (1966, 1979) have considered the *pros* and *cons* of irradiation as a means of controlling stored product pests. The high cost of irradiators limits their use to sites where reasonable frequency of use and throughputs are assured.

The advantages, disadvantages and uncertainties of irradiation, as currently perceived by an exporter such as Australia, are as follows:

Advantages

1. Does not leave toxic residues within the grain or its products.

2. Does not adversely influence the wholesomeness of the grain or its products.

3. Is a rapid process that can be scaled up to treat grain flowing at several hundreds of tonnes per hour.

4. Is suited to automatic operation in which the required dosage is applied consistently to all grains within each infested batch.

5. When properly engineered, is safe to use.

6. Uses little energy and, hence, is competitive in running costs with conventional control measures.

7. Is effective against pests that are resistant to other control measures such as insecticides and fumigants.

8. If an appropriate dosage is chosen and consistently administered, the risk of pests becoming resistant to irradiation is small.

Disadvantages

1. Capital cost is high, e.g, at least US $1 million for a 150/200 t h^{-1} accelerator-based plant.

2. Does not kill insects immediately and therefore fails to meet current requirement for freedom from live insects at export and, depending on voyage time, on receival overseas.

3. Efficacy of treatment is difficult to check because a practicable method of determining whether insects are sterile or otherwise is lacking.

4. Provides no residual protection against re-infestation after treatment.

5. Is harmful to germination and, therefore, could not be used on cereals for seed or malting.

Uncertainties

1. Influence of irradiation on functional properties of Australian wheat is not well known.

2. Willingness of importing plant quarantine authorities to accept irradiated grain containing live but sterile insects has not been determined.

3. Acceptability of irradiated grain to domestic and overseas consumers is undetermined.

4. Legislation permitting its use in Australia has not been generally enacted.

5. Acceptibility of irradiation to grain industry/shipping workers is not known.

Use of irradiation at export terminals would appear to depend in part on either the willingness of importing countries to accept irradiated grain containing live but sterile insects or the provision of sealed storages in which the irradiated grain could be held for some weeks prior to export while the insects die.

Such problems do not arise at import terminals or quarantine facilities where the treatment is applied by the importer or his agent and a certificate of treatment can be issued by, for example, a government quarantine or plant health inspector in the knowledge that the irradiated insects will eventually die and the amount of damage caused by them will be small.

THE FUTURE

Over the years, research has generated a broad but not inexhaustable range of control methods that allow dependence on insecticides to be reduced (Winterbottom, 1922; Evans, 1982). The challenge to both 'research' and 'industry' is to integrate existing and new control measures, such as irradiation, into rational and powerful systems of quality and pest management that are sympathetic to but not dominated by the constraints of current production systems. Success will depend greatly on the level of communication between the parties involved in pest control and their willingness to work together.

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Table 1 Limiting and optimum conditions for increase of populations of certain insect and mite pests of stored pulses and cereals

Species	Common Name	Minimum temp. (°C)	Minimum r.h. (%)	Optimum temp. (°C)	Optimum r.h. (%)	CT	D	Susceptibility of products to attack (see key below) C	C*	C**	c	P	p
				OPTIMUM TEMPERATURE < 30°C									
Acanthoscelides obtectus (Say.)	dried bean beetle	14	30	27 - 31	65							x	
Acarus siro L.	flour mite	7	65	21 - 27	80	x			x		x	x	x
Ephestia elutella (Hubn.)	warehouse moth	10	30	25	70	x	x		x		x		x
Ephestia kuehniella Zeller	Mediterranean flour moth	10	1	24 - 27	65	x	x		x		x		
Ptinus tectus Boield.	Australian spider beetle	10	50	23 - 25	70	x			x		x		x
Sitophilus granarius (L.)	grain weevil	12	50	26 - 30	70	x		x					
Sitophilus oryzae (L.)	rice weevil	14	60	27 - 31	70			x					
Sitotroga cerealella (Oliv.)	Angoumois grain moth	16	30	26 - 30	-	x	x	x					
				OPTIMUM TEMPERATURE > 30°C									
Callosobruchus chinensis (L.)	cowpea beetle	17.5	30	28 - 32	60							x	
Callosobruchus maculatus (L.)	cowpea beetle	20	30	30 - 35	50							x	
Corcyra cephalonica (Staint.)	rice moth	18	30	28 - 32	30				x		x		
Cryptolestes ferrugineus (Steph.)	rust red grain beetle	20	10	32 - 35	65	x	x		x		x		
Cryptolestes pusillus (Schon.)	flat grain beetle	20	60	28 - 33	70				x		x		
Ephestia cautella (Wlk.)	tropical warehouse moth	17	25	28 - 32	60		x		x		x		
Lasioderma serricorne (F.)	cigarette beetle	20	30	32 - 35	55						x	x	
Latheticus oryzae Waterh.	long-headed flour beetle	25	30	33 - 37	-		x			x	x		
Oryzaephilus surinamensis (L.)	saw toothed grain beetle	20	10	31 - 34	65	x			x		x		
Plodia interpunctella (Hubn.)	Indian meal moth	18	40	28 - 32	-		x		x		x		
Rhyzopertha dominica (F.)	lesser grain borer	20	30	32 - 35	50			x			x		
Tribolium castaneum (Herbst.)	rust red flour beetle	20	1	32 - 35	65					x	x		x
Tribolium confusum Duv.	confused flour beetle	17	1	30 - 33	50					x	x		x
Trogoderma granarium Everts.	khapra beetle	22	1	33 - 37	45	x	x	x			x	x	x
Zabrotes subfasciatus (Boh.)		20	30	29 - 33	50							x	

Key:

C - whole undamaged cereals

C* - germ of cereals

C** - cereal grain already damaged mechanically or by other insects

c - cereal products

CT - cold tolerant

D - a species with diapause

P - whole pulses

p - pulse products

Table 2. Some commonly used insecticides.

INSECTICIDE	Usage					Dosage
	KD[*]	SS	ST	GP	GT	g/t
azamethiphos	+		+			
bioresmethrin [a]	+			+		1
bromophos				+		6-10
carbaryl			+	+		5-8
chlorpyrifos-methyl			+	+		4-10
cypermethrin [a]	+	+	+	+		1-2
deltamethrin [a]	+	+	+	+		0.2-2
diazinon			+			
dichlorvos	+		+	+	+	4-12
etrimifos	+		+	+		4-10
fenitrothion			+	+		6-12
fenothrin [a]	+	+	+	+		1-4
fenvalerate	+	+	+	+		1-4
lindane	+	+[b]	+			
malathion		+	+	+		8-16
methoprene	-	-	-	+		0.5-10
methacrifos	+	+	-	+		4-20
permethrin [a]	+	+	+	+	+	1-4
pirimiphos-methyl		+	+	+		4-6
propoxur			+[c]		-	
pyrethrins	+	+	+	+	+	2-3

a generally synergised with piperonyl butoxide

b bag surfaces only

c for cockroaches

* see text for headings

LECTURE 14

APPLICATION OF GAMMA-IRRADIATION TO CEREALS & CEREAL PRODUCTS

M. WOOTTON

APPLICATION OF GAMMA-IRRADIATION TO CEREALS AND CEREAL PRODUCTS

Dr. M. Wootton
(1985)

SUMMARY

Gamma-irradiation may be used on cereals and cereal products to control insect infestation and microbiological problems. Such problems include mould growth, mycotoxin production, pathogens, spore-forming organisms and total microbial load. Deleterious effects of gamma-irradiation arise only at relatively high dose levels with consequences on germination rate, wheat flour dough properties, and cake and noodle quality. Radiation-induced changes to starch have greater impact on behaviour of cereal products than such changes to other cereal components.

1. INTRODUCTION

Cereals and cereal products are mostly stored at moisture contents below approximately 14% and hence microbial spoilage is usually not a problem. The most serious losses of such materials are caused by insects. However, cereals may carry microbial loads which become a problem when incorporated into wet formulations especially since pathogens such as Salmonellae may be present. This is of particular interest in stockfeed formulations which may not receive a heat process and the pathogens may infect livestock for human consumption. Occasionally grains and their products are stored at moisture contents sufficient to allow mould growth. This of itself will cause losses but may allow production of mycotoxins such as the aflatoxins.

Irradiation of cereals has great value in combatting all problems outlined above. As with other foods, factors such as nutritive value, safety, sensory acceptability and dosage necessary must be considered in deciding on treatments applied. However, cereals differ from most other foods in that they possess a range of functional properties essential to their processing and application. Thus final treatments applied must be dictated by dose levels which will not damage these functional properties.

2. BENEFICIAL EFFECTS OF GAMMA-IRRADIATION ON CEREALS AND CEREAL PRODUCTS

2.1 Entomology Aspects

Damage caused by insects during cereal storage includes:

- consumption of the grain itself,
- contamination of the product with insect fragments, excreta etc.,
- damage to storage structures and containers,
- heat and moisture generation in storage,
- transfer of human diseases.

In the United States alone between 1951 and 1960, average loss per year due to insect damage was estimated at almost $500,000,000. Worldwide the figure can only be guessed but must be much higher. An average of 10% of harvested foods are destroyed in storage by insects with losses of 30% common in some areas. There are approximately 20 different major insect species causing damage to stored grain and approximately 30 involved in a minor way.

At present, chemical control of insects by insecticides and fumigants is the most widely used safeguard. Such agents include inert dusts, malathion, pyrethrins, pyrethoids, dichlorvos, phosgene and ethylene dibromide. However the problems of pesticide residues and the toxicity of these materials to humans has led to considerable interest in decreasing their usage (Christensen, 1982). The most promising alternative to these materials appears to be gamma-irradiation.

A comprehensive review of gamma-irradiation on the entomology of cereals is provided by Josephson and Peterson (1983). Most insects in stored grain will be inactivated by 0.5 kGy although a few may reproduce after irradiation with doses as high as 0.9 kGy (FAO/IAEA, 1982). It is important to note that irradiation at these levels is not immediately lethal nor is there any protection given against reinfestation.

2.2 Microbiological Aspects

Microorganisms which may infect cereals and their products include bacteria, protozoa, slime moulds, yeasts and fungi. Of these, bacteria and fungi represent greatest problems. Bacteria are rarely causes of storage losses and are of most interest from the point of view of pathogenic considerations or possible spoilage in high moisture, unheated products. Some bacteria can inhibit such germination (Christensen, 1982).

Some fungi on the other hand are adapted to low moisture environments. These include some species of Aspergillus, Alternaria, Cladosporium and Fusarium. The effects of fungi include reduced germination, discoloration of the grain, respiration and heating and ultimately, total decay. In addition, there is the possibility of the production of toxins such as aflatoxins, ochratoxin, zearalenones, tricothecenes and vomitoxin (Christensen, 1982).

Control of microorganisms is primarily achieved by controlling moisture content and temperature during storage. The most frequently used chemical agents for mould prevention are propionic acid and its salts, although ammonia gas has been shown to be effective (Christensen, 1982).

The use of gamma-irradiation to control microbiological problems associated with cereals and their products requires approximately 10 times the dose rates for insect control.

Examples of this are shown in Table 1 where it can be seen that doses between 0.5 and 10 kGy are necessary to provide effective microbiological control in various situations. It is significant that the use of heat in combination allows substantial reduction in dose rates, e.g. irradiation of bread at 65°C with a dose of 0.5 kGy give equivalent prevention against mould to 5 kGy without heating. For the purpose of eliminating human pathogens from stockfeed a dose of 7.5 kGy, giving a 5-decimal reduction in Enterobacteriaceae has been proposed (FAO/IAEA, 1982).

3. EFFECT OF IRRADIATION ON CEREAL COMPONENTS

3.1 Starch

The effects of gamma-irradiation on starch have received considerable attention and are summarised in Table 2 for doses up to 10 kGy. Higher doses, up to 250 kGy, on maize starch have been shown to produce a number of carbonyl compounds (Raffi *et al.*, 1981) and fairly complex mixtures of sugars (Berger *et al*. 1973).

Doses of up to 10 kGy resulted in decreased starch yield and quality from maize (Roushdi *et al*. 1981). This in conjunction with changes to starch properties listed in Table 2, is of great importance to the starch processing industry. It appears that the amorphous regions of the granule are more easily degraded by radiation to produce "radiodextrins" than are the crystalline regions (Robin *et al*. 1978).

3.2 Proteins

It appears that doses of up to 10 kGy have very little effect on total amino acids of cereal proteins. An increase in free sulphydryl groups in rye was reported for doses up to this level (Harubala and Walat, 1970). At 10 kGy doses, wheat displayed an increase in free amino acids and some evidence of a shift to lower molecular weight in the protein fraction was observed (Srinivas _et_ _al_. 1972).

Of particular interest to the Australian scene is the effect of radiation on gluten recovery from wheat flour. Table 3 shows the effect of 6.5 kGy doses of gamma radiation on thirteen different wheat varieties (Lee, 1960). It can be seen that yields were decreased by between 10 and 48% amongst the varieties. It is significant that the greatest loss occurred with the low protein Pacific Club variety. Because of the obvious influence of variety and the use of both Martin and batter processes for starch/gluten separation in Australia, considerable work should be carried out in this area before irradiation is applied commercially to wheat destined for starch-gluten separation.

Doses of greater than 70 kGy were needed to cause decisive structural changes to dry gluten while approximately 1 MGy was needed to destroy all gluten properties of importance to the baking industry (Laztity and Figuli, 1969).

3.3 Lipids

No changes in fatty acid pattern or free fatty acid levels occurred after up to 50 kGy doses of gamma-irradiation of wheat (Tipples and Norris, 1965). Doses of up to 20 kGy were found to produce no off flavours in wheat although an increase in free lipid and a decrease in bound lipid occurred (Rao _et_ _al_. 1979). Irradiation does not therefore seem likely to cause problems with lipid fractions.

4. FUNCTIONAL PROPERTIES OF IRRADIATED WHEAT FLOUR

Irradiated wheat flour has lower maximum amylograph viscosity, and its mixing behaviour indicates higher water absorption, longer development time, increased dough stability and greater dough consistency for doses up to 2 kGy (Rao _et_ _al_. 1978).

Bread quality seems satisfactory for flour irradiated with doses of up to 10 kGy (Milner, 1961) while acceptability of biscuit products appears to be little affected by doses of up to 5 kGy (Cornwell, 1959).

It seems however that in products where starch gelatinisation, rather than gluten development, plays a dominant role, radiation treatment leads to serious deleterious effects. Cake flour treated with doses above 4.65 kGy gave drier batters and cakes which had lower volume, dipped in the centre and had heavy, gummy texture (Brownell et al. 1955). Noodles prepared from flours treated with 0.2-1.0 kGy had poorer flavour, odour and mastication properties than control samples. Greater losses occurred during cooking of products made with irradiated flour (Shibata et al. 1974).

The potential impact of irradiation on starch/gluten separation was referred to briefly in the section above on proteins. It would appear that the doses sufficient to treat insect infestation may not have significant effects on the gluten, but starch yield and properties may be affected.

5. IRRADIATION OF RICE

A comprehensive study of the effects of gamma-irradiation on rice was reported by Wang et al. (1983). These workers found that radiation doses of 1-3 kGy extended storage life of three rice varieties (11.5-13.3% moisture content) up to 2 years. Research using higher moisture paddy is not apparent in the literature at present but is of great importance. The results of Wang et al. (1983) are summarised below.

No change in milling yield of the rice was reported after irradiation however germination rate decreased at dose rates above 0.5 kGy. The radiation treatments also significantly decreased the survival of microorganisms on the grains, and doses over 0.5 kGy effected complete sterilisation of insect eggs.

In terms of chemical changes, no effects were reported on protein or starch for doses up to 3 kGy. Radiation had no effect on free fatty acid production during storage nor on reducing sugar or thiamine levels. Gamma-irradiation did however cause some decrease in α-amylase activity in the grain.

Cooking quality was assessed by examining rice colour, fragrance, water absorption during cooking and pH of the cooking water. Colour and fragrance were unaffected by radiation with doses up to 3 kGy except for one variety which developed a yellowish colour and slightly disagreeable odour at the highest dose. pH of the cooking water remained constant at about 6-6.8, being unaffected by either radiation treatment or subsequent storage. Some fluctuations in water absorption were observed at different dose rates and during storage but these appear to be rather small.

6. GRAIN VIABILITY AND BIOCHEMISTRY

Grain viability has obvious and important ramifications for both the seed and malting points of view. Germination of rice grains was reduced considerably by exposure to doses in excess of 0.5 kGy (Wang *et al*. 1983). Dose levels of 5.81 kGy reduced germination of wheat by 80% (Lorenz, 1975). The latter also reported that grain respiration decreased at this dose level.

In a study of the effect of gamma-irradiation on barley germination, it was found that 0.7 kGy was the optimum dose level to inhibit radicle and germ growth, reducing malting losses by 13-22% (Marseu and Cojocaru, 1972).

Reports on the influence of irradiation on enzyme activity are relatively sparse. However doses of 8 kGy completely inhibited α-amylase activity in wheat (Kiss and Farkas, 1977) while doses above 0.3 kGy decrease the activity of this enzyme in rice (Wang *et al*. 1983). Proteolytic activity in rye also decreased by up to 36% when the grain was exposed to doses as high as 10 kGy (Harubala and Walat, 1970).

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Table 1. Control of microbial problems by gamma-irradiation.

Product	Dose (kGy)	Effect
Wheat (15% mc)*	2.5	Mould retarded
Maize*	6.0	Mould prevention
Sorghum*	6.0	" "
Bread (sliced, wrapped)	5.0	Mould free 11 weeks
Bread (sliced, wrapped)	0.5 at 65°C	Mould free 11 weeks
Chapaties*	10.0	Mould free after 6 months
Bread*	2.0	Prevention of aflatoxin production by *A. parasiticus*.
Rice, maize starches*	3.0	Reduction in bacterial count
Animal feeds*	7.5	Five-decimal reduction in enterobacteriaceae
Bread**	0.75-1.5	Rope spore development control.
Rice†	1-10	Reduced total plate count.

* FAO/IAEC (1982)

** Farkas and Andrassy (1981)

† Wang *et al*. (1983)

Table 2. Effect of gamma-irradiation up to 10 kGy on starch.

Product	Effect on Starch	Authors
Wheat	Increased susceptibility to Amylases	Anathaswarmy *et al*. (1970)
	Decreased anylograph viscosity	Milner (1957)
	Decreased viscosity	Deschreider (1960)
	Increased reducing power	
	Increased amylopectin solubility	
Rice	Gelatinisation temperature decrease	Chaudhry and Glew (1973)
	Granule density decrease	
	I_2 binding decrease	
	Average chain length decrease	

Table 3. Effect of gamma-radiation (6.5 kGy) on gluten recovery from various wheat flours.

Wheat Variety	Gluten recovery (%)		Loss in yield due to irradiation (%)
	Before	After	
Pacific Club	6.2	3.2	48
Rio Nigro	18.4	16.0	13
Certana	12.3	9.7	21
Redman	14.3	11.5	20
Mida	12.8	10.0	22
Lake	12.8	10.3	20
Chinook	14.7	13.3	10
Thatcher	12.7	10.9	14

From : Lee (1960)

LECTURE 15

IRRADIATION OF SPICES & HERBS

C. SAUL

AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

IRRADIATION OF SPICES AND HERBS

CHRISTINE SAUL
1985

INTRODUCTION

Spices and herbs are employed as raw materials in most categories of the food industry including semi-processed and processed meats, fish products, convenience foods and bakery products.

Owing to their origin many of these materials are highly contaminated with micro-organisms which include moulds, yeasts and bacteria.

In general allspice, basil, caraway, celery seed, cumin, black pepper and dehydrated onion powder are found to contain the highest viable counts of the order 10^6 to 10^8 per gram. Although these spices are employed as minor ingredients (of the order 0.1 - 2%) in food products, they nevertheless contribute a significant population of micro-organisms which find an ideal culturing medium in many semi-processed and even processed foods. And, as a result, they can cause food spoilage. The food industry has been concerned for many decades with finding methods to decontaminate spices.

CONVENTIONAL DECONTAMINATION METHODS

A number of decontamination methods have therefore been applied in the past, and some are still employed, to spices used in the food industry.

Heat - (Dry) and Steam Treatment

This very common food sterilization method has been widely applied mainly because of its use in the last stage of processing canned foods to which the spices have been added. A disadvantage to heat is that volatiles are sometimes lost or altered.

UV/ELECTRON BEAM/MICROWAVE IRRADIATION

UV Irradiation has been demonstrated as an effective decontamination method for spices but its use is highly limited because of the low penetration into an essentially opaque material.

Similarly Electron beam irradiation is highly effective but in this case too, only thin packages can be irradiated thus limiting the potential of the method.

Microwave irradiation is more penetrating than UV or electrons. However since the moisture in spices and seasonings is rather low (4.5 - 12%) and the effect of this method is based on heat generation in the presence of moisture, microwave irradiation has been shown ineffective and insufficient.

CHEMICAL TREATMENT

Chemical agents have been and are still widely used for decontamination of spices. The more common gas employed is ethylene oxide. This treatment has been found effective for the disinfestation of spices as well as for reduction of bacterial populations. However in recent years questions have been raised about this gas. New regulations controlling EtO in the U.S. were published in 1984. These regulations limit worker exposure to 1ppm or less in an 8 hr. day. This is difficult to achieve in a bulk food product. In addition, while EtO is effective, it is not always efficient. The following slides show what happens to onion powder when it is EtO treated. Onion powders are very dry, (4.5 - 5.5% moisture). EtO needs a moisture content of 7 - 8% and therefore the powder cannot be gassed in containers. It is dumped onto long thin trays and put into chambers. The final 'block' must then be ground.

Ethylene dibromide has been used as a chemical fumigant. The cancellation and phase-out of ethylene dibromide by the U.S. Environment Protection Agency has led to a need for alternative treatments.

GAMMA IRRADIATION

Sterilizing by ionizing radiation has a major advantage in that it is a cold treatment. Irradiation dosage as high as 50 kGy will only increase the temperature of irradiated food by 12°C. Therefore there is little danger of the loss of volatile components of the spice. The irradiation process has the advantage that it doesn't require the addition of any chemicals, liquid or gas to the spice.

When McCormick became interested in Gamma Irradiation they looked for any changes in :

Microbiology.
Chemistry
Mutagenicity.
Sensory.

MICROBIOLOGY

The most common bacteria in spices are the anaerobic spore formers, such as the Bacillus species, accompanied in some instances by Clostridium or Salmonellae. The most common moulds are the Penicillin species, Rhizopus and some of the Aspergillus group.

A representative group of spices was analysed in the McCormick laboratories for microbial contamination before and after gamma irradiation.

TABLE I - presents an overview of results.

The results obtained for dehydrated onion powder are given in detail in TABLE II.

The spices were irradiated at an average dose of 10 kGy except for paprika and crushed red pepper which were irradiated at an average dose of 6.5 kGy. It was found that this dosage was sufficient to reduce the microbial population of the capsicums to acceptable levels.

A recent study undertaken in Malaysia on black and white pepper (TABLE III) yielded similar results using a dosage of 9 kGy for black pepper and 6 kGy for white pepper. White pepper having a lower microbial loading than the black pepper, therefore requires less dosage.

In a commercial scale-up last year, McCormick processed 40,000 lbs. of various onion powders in 80 x 50 lb. boxes at the U.S. permitted dose of 10 kGy max. (Average dose 7 kGy). The onion was very high in bacteria with an average SPC of about 7 million. The average percentage reduction of micro-organisms was approximately 98%.

CHEMISTRY

Dry products such as spices are less affected chemically by dry irradiation than high moisture foods such as beef and whole fruits. In spices which are dehydrated or contain little water, direct action of irradiation by dissipation of energy within the molecules of the food constituents takes place. However, the major constituents are protected. Generally, impractically high radiation doses would be required to form significant levels of radiolytic products in irradiated dry solids or powders. We tested the effects of irradiation on onion powders irradiated up to 270kGy and found that onion powders proved very resistant to chemical change.

Extensive chemical analysis of dehydrated onion powders, (TABLE IV) revealed very few chemical changes in that spice when irradiated at an average dose of 10kGy constituents investigated were volatiles, amino acids, sugars, starch, carbohydrates, proteins and fats.

Chemical analyses on other spices and herbs was undertaken (TABLE V). Percent moisture and volatile oils were determined for each spice. In addition non-volatile essential oil and UV piperine were run for black pepper.

Similar observations were made in a recent Malaysian study where gamma irradiation with a dose up to 9 kGy did not have a significant effect on the moisture content of black or white pepper (TABLE VI).

Most spices are needed for flavouring foods - however the acceptability of paprika depends largely on its colouring properties. Extensive studies have been carried out to monitor the effect of irradiation on the colouring pigment capsanthin, in paprika. In Shelf Life studies, the paprika samples have shown no difference at 6 months storage and storage temperatures of 40°, 75° and 90° F. (Hunter Colour and Sensory Evaluation).

SENSORY EVALUATION

Spices are used to provide flavour to foods both industrially and in the home. The amount of spice used in a product depends entirely on the flavour and strength desired by the consumer.

Generally speaking spices form very small amounts of the total human diet - less than 0.2%. It is of prime importance that the flavour of spices is not adversely affected by any treatment undertaken.

McCormick has done extensive sensory evaluation analysis for its entire line of spice products. The following standard procedures were used to test for differences in sensory characteristics between irradiated spices and controls.

1. Bench top evaluations.

Samples were visually examined by trained staff to note any difference in appearance - colour, particle size, composition etc., before and after preparation.

2. Sensory Panel

(a) Triangle Tests.

Most samples were tested using balanced triangle test designs to compare the flavour of controls to the irradiated test sample.

(b) Paired Comparison.

For black pepper only a paired comparison test design was used to minimise sentory fatigue and carry over.

(c) Red Pepper.

The red pepper samples were evaluated for heat content using a method developed by McCormick. The method involves an aqueous extraction of the pepper in hot water with polysorbate - 80, dilution, and tasting in comparison to a standard reference solution of vanillyl nonamide.

Analysis of Results

Results of all sensory tests were analysed statistically. Few differences were found in any of the spices tested: Onion Powder; Paprika; Other Spices.

As a further check of the sensory properties of irradiated spices, all samples were evaluated in 3 types of food application, hot; hot/cold treated; refrigerated (24 hours) and cold. In the applications tested, no major differences were found.

WHOLESOMENESS

The term 'Wholesomeness' which is applied to irradiated foods has acquired the meaning of nutritional quality, toxicological safety and microbiological safety. Considerable Wholesomeness studies have been undertaken on irradiated spices.

These studies are often divided into mutagenicity testing and feeding studies.

Mutagenicity tests were conducted by McCormick on dehydrated onion powders. They include :

1. The Ames Test.
2. In vivo Sister Chromatid Exchange.
3. Drosophila malanogaster.

No adverse effects were found in any of the tests.

Animal feeding tests conducted with pungent materials such as many of the important spices and herbs are extremely difficult and in some cases impractical, particularly at the high levels of solids intake required. In a number of cases, in both short and long term feeding studies, investigators found various toxic effects due to components in the spices rather than due to irradiation.

The feeding studies on all irradiated spices indicated no adverse effects from irradiated material.

PEST INFESTATION CONTROL

The effects of gamma irradiation on pest infestation control has been part of 2 research studies in the Asian Regional Co-operative Project on Food Irradiation.

Both studies concluded that irradiation in combination with good packaging materials helped arrest insect development.

Polypropylene bags, particularly the ones without inner liners were unable to withstand reinfestation during shipment.

Polyethylene bags of 0.17mm thickness were successful in maintaining low levels of infestation brought by gamma radiation. The extra thickness of the packaging afforded extra durability required for safe handling during transportation.

Tin containers were able towithstand rough handling and prevent reinfestation. Oxygen absorbers were experimented with in spice packages but had no effect on microbial load, chemical or orgaoleptic qualities of spices.

CONCLUSION

Studies and commercial activities in recent years in several countries have demonstrated that irradiation of spices and condiments is technologically and economically feasible.

This process has been shown to be safe and wholesome with no effect on product quality or flavour.

When irradiation is approved world wide the process will find entry for a limited number of products, including spices. It will be a valuable process for those products difficult to clean by other means and it will help provide a safe wholesome food supply for the world's population.

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Listed Separately are the research papers and the references cited by Dr. Eiss.

Both research Papers result from the Asian Regional Project on Food Irradiation.

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TABLE I

MICROBIOLOGICAL DATA : IRRADIATED SPICES

Spice	(kGy)	Standard plate count	Yeast	Mould	MPN coliforms
Allspice	0	2,278,000	<10	0	0
	10	<10	<10	0	0
Greek Oregano	0	1,214,400	40,000	9,000	2,636
	10	<10	<10	<10	0
Black Pepper	0	32,000,000	0	0	25
	10	60	0	0	0
Garlic Powder	0	414,000	<10	7,800	0
	10	700	<10	<10	0
Egyptian Basil	0	3,000,000	>30,000	400	>11,000
	10	1,000	<10	<10	0
Thyme	0	150,000	0	300	30
	10	40	0	<10	0
Mexican Oregano	0	1,500,000	>30,000	10,000	5,000
	10	30	<10	<10	10
Domestic Paprika	0	1,000,000	0	0	0
	10	100	0	0	0
Spanish Paprika	0	2,200,000	0	0	410
	10	260	0	0	0
Celery Seed	0	440,000	1,500	200	25,000
	10	<10	<10	<10	0
Crushed red pepper	0	130,800	<10	0	0
	6.5	<10	<10	0	0

TABLE II

MICROBIOLOGICAL DATE : IRRADIATED ONION POWDER

Standard microbiological analysis	Control	Irradiated*
Standard plate count	480,000	2450
Mould	201	ND¶
Escherichia coli	1.1	ND
Faecal coliforms	30	ND
Total Coliforms	1,157	ND
Confined Coliforms	964	ND
Yeast	ND	ND
Thermophiles		
Aerobic spores	6.6	ND
Aerobic flat sours	0.2	ND
Anaerobic spores	0.3	ND
Anaerobic flat sours	10.8	ND
Mesophiles		
Aerobic spores	33	ND
Aerobic flat sours	25	0.3
Anaerobic spores	15	ND
Anaerobic flat sours	81	1.0

* Samples irradiated at average dose 1 Mrad (10 kGy)

¶ Not detected.

TABLE III

MICROBIOLOGICAL DATE : IRRADIATED BLACK & WHITE PEPPERS*

Spice	Std. Plate Count	Total Yeast and Mould Count
Balck Pepper		
0 kGy	15,700,000	21,900
9 kGy	2,900	LT 100¶
White Pepper		
0 kGy	22,700	21,000
4 kGy	LT 100	LT 100¶

¶ Samples irradiated at 2 kGy

* Mohd Khan Ayob, Ismail Bin Bahari

TABLE IV

CHEMICAL ANALYSIS : IRRADIATED ONION POWDER*

Constituent	Control (%)	Irradiated ($%)
Protein	10.80	10.80
Moisture	5.50	5.62
Fat	1.00	1.15
Ash	3.72	3.72
Crude Fibre	4.85	4.87
Carbohydrate	74.13	73.87
Calories	348.83	349.17
Starch	3.31	2.96
Total Sugars (sucrose)	63.27	63.70
Total Sugars (dextrose)	66.57	67.07

*Samples irradiated average dose 1,000 Krad (10 kGy)

TABLE V

CHEMICAL ANALYSIS : IRRADIATED SPICES

Spice	Control (%)	Irradiated (%)
Egyptian basil		
VODS*	1.14	1.13
Moisture	7.81	8.01
Spanish Thyme		
VOSD	1.28	1.29
Moisture	8.83	9.10
Domestic Paprika		
Moisture	11.03	11.03
ASTA Colour Value¶	117.00	115.00
NVEE§	8.52	8.36
Mexican oregano		
VOSD	5.49	5.46
Moisture	6.19	6.40
Black Pepper		
VOSD	1.15	1.16
NVMcEØ	9.16	9.18
Moisture	8.63	8.71
UV Piperine	6.57	6.56
Spanish Paprika		
Moisture	9.50	9.43
ASTA Colour Value	116.00	115.00
NVEE	11.95	12.07
Greek Oregano		
VOSD	2.02	2.00
Moisture	8.26	8.50
Celery Seed		
VOSD	2.58	2.50
Moisture	5.00	5.00
Allspice		
VOSD	3.38	3.26
Moisture	8.32	8.94
Crushed Red Pepper		
Moisture	8.82	8.92
Water activitiy (a_w)	0.65	0.57

* Volatile oil steam distilled.
¶ American Spice Trade Association.
§ Non-volatile ether extract.
Ø Non-volatile methylene chloride extract.

TABLE VI

CHEMICAL ANALYSIS : IRRADIATED BLACK & WHITE PEPPERS*

Spice	Control	Irradiated (9 kGy)
Black Pepper		
% Moisture	16.65	10.70
White Pepper		
% Moisture	10.59	10.59

* Mohd Khan Ayob, Ismail Bin Bahari

LECTURE 16

IONISING ENERGY TREATMENT OF CARCASSES, PACKAGED FRESH MEAT & PROCESSED MEATS

A. EGAN

AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

IONISING ENERGY TREATMENT OF CARCASSES, PACKAGED FRESH MEAT AND PROCESSED MEATS

(1985)

A.F. EGAN
CSIRO Division of Food Research, Meat Research Laboratory,
Cannon Hill, Queensland, 4170

INTRODUCTION

Meat has long been considered to be a nutritious and very desirable food and it is a major component of the diet in Australia. In 1984 the per capita consumption of red meat was 76 kg compared with 20 kg for poultry meat and about 7 kg for fish.

Meat consists of the muscular tissue and associated fat of so-called "red meat" animals and most commonly is regarded as the edible portions of the carcass of sheep, goats, pigs or cattle. It provides an excellent nutrient substrate for a wide range of micro-organisms. Since muscle contains about 75% water, bacteria are able to grow readily to high populations and cause rapid spoilage. The bacteria commonly present on, or able to grow on, meat may be pathogenic and meat is still a major cause of foodborne disease.

At present ionising energy treatment does not appear to be used commercially to improve the microbial quality of red meats. In this paper the possibilities of using it to increase the storage life and to reduce the public health hazards associated with meats are discussed. More detailed background information can be found in articles by Ingram and Roberts (1980), Urbain (1978) and Wills (1982).

GENERAL ASPECTS OF THE TREATMENT OF MEATS WITH IONISING ENERGY

In a healthy animal, the muscular tissue is sterile. During slaughter and processing the carcass is contaminated with organisms from the intestinal contents and the abattoir environment. Thus contamination is largely confined to the surface, but during boning the bacteria are transferred onto the cut surfaces.

The surface nature of the bacterial contamination of meats means that treatment using accelerated electrons may be suitable. Since these do not penetrate to the same extent as gamma irradiation, use of this technique would minimize organoleptic changes. However the shape of carcasses may mean that some surfaces do not receive an adequate dose (e.g. inside the chest cavity).

When fresh meat is stored in air it spoils rapidly due to the growth of Gram-negative aerobic bacteria which cause putrefaction. These and the common pathogenic organisms found on meat are not radiation-resistant and hence low doses (up to 5 kGy) are effective either for radurization or radicidation of meat.

Two problems appear to limit the use of irradiation for meats. Ionising energy treatment of meat causes changes in flavour, aroma and colour. These may alter the product sufficiently to cause problems with consumer acceptance. When evaluated by trained analytical taste panels, the changes become statistically significant at quite low doses of about 2-2.5 kGy. The significance of taste panel results in terms of consumer perceptions is difficult to assess. Almost certainly the panel is more discriminating than an individual consumer if only because the panel operates in an experimental situation and compares the test samples to ones which have not been irradiated.

Organoleptic changes can be limited by irradiating the meat chilled or (even better) frozen (Urbain, 1978; Kampelmacher, 1983). Packaging will also assist in this regard since lower oxygen concentrations will be present during treatment.

Other problems with fresh meats are the chemical and biochemical changes which can occur during storage (also discussed further later). Enzymes are usually not inactivated by irradiation at bactericidal dose levels (Ingram and Roberts, 1980). This problem does not occur with meats in which the enzymes have been inactivated by cooking or some other processing procedure.

Following irradiation, meats may be readily recontaminated with bacteria. This problem can be avoided by packaging prior to treatment. Vacuum-packaging and similar techniques are now very widely used with a large range of both fresh and processed meats.

One general problem which occurs with the irradiation of packaged meats, is the growth of a secondary flora of organisms which survived the treatment. These may include Moraxella, lactic acid bacteria and yeasts. When spoilage of treated meats does occur it may be due to quite different organisms to those normally present and thus may be very different in nature. While insect contamination is not usually a problem with meats, parasites may be present. These may include the causative agents of trichinosis, taeniasis and cysticercosis. These are destroyed or inactivated by quite low doses of irradiation (discussed by Dempster, 1985).

DESTRUCTION OF PATHOGENS

The Gram-negative pathogens found commonly on meats include Salmonella, enteropathogenic Escherichia coli, Yersinia enterocolitica and Campylobacter jejuni. These organisms are sensitive to irradiation. Recently Tarkowski et al. (1984) determined D-values for strains of Salmonella, Y.enterocolitica and C.jejuni isolated from beef. They showed that a 1 kGy treatment of ground beef caused a reduction of more than 95% in the number of viable Salmonella cells present. Corresponding reductions in the number of the other two organism exceeded 99.99%. Since these organisms are usually only present in small numbers, they can readily be reduced to undetectable levels by small doses.

Clostridia may grow within meat tissue especially at temperatures above 20°C and cause obnoxious anaerobic putrefaction. This is an indication that pathogenic species especially Clostridium perfringens and Clostridium botulinum may have grown.

Cl.botulinum produces spores which are resistant to irradiation. To eradicate this very dangerous organism a sterilizing dose is required. Alternatively a lesser dose may be used if assisted by other factors such as low pH or the presence of curing salts (sodium nitrite). In thermal processing of foods (meat canning) an inactivation of 10^{12} (the so called 12D concept) is aimed for with this organism. To achieve this using ionising energy a dose of about 45 kGy is needed (Ingram and Roberts, 1980). This organism must be eliminated if fresh or carcass meats are to be stored at room temperatures (unrefrigerated) but the organoleptic side effects of this level of treatment cause problems.

On cured and processed meats Staphylococcus aureus is a common problem because it can tolerate high salt concentrations. It is only slightly more resistant to ionising energy than Salmonella.

With the exception of Y.enterocolitica, the organisms mentioned above are all mesophiles and thus do not grow below about 8°C. This needs to be considered when deciding upon possible ionising energy treatments for meats. In many cases the final procedure will be one combining the use of irradiation with appropriate packaging and low temperature storage.

TREATMENT OF CARCASSES OR CUTS OF FRESH MEATS

The flora on refrigerated fresh meats is composed predominantly of Gram-negative bacteria, *Enterobacteriaceae* and *Pseudomonas* spp. The latter become dominant as storage progresses and cause putrefactive spoilage which usually becomes significant when numbers reach about $10^7/cm^2$. Even with a low initial count, the storage life at 0-2°C is only about one week.

These organisms are sensitive to irradiation and a dose at 0.5-1 kGy can extend the storage life about four fold i.e. up to about 4 weeks at 0-2°C (Wolin *et al.*, 1957). This level of dose causes no signficant organoleptic changes and it was clear by the mid-1960's that radurization was a suitable process for the preservation of fresh meat.

On-line irradiation of carcasses appears to present no major technical problems. In Australia a typical abattoir produces about 350-400 beef cattle carcasses per day (range ca. 200-1000). Assuming an average carcass weight of 200 kg, the radiation facility would need to be of sufficient capacity to treat about 80 tonnes of meat a day. Many works also process sheep and a typical large abattoir might produce a total of 160-200 tonnes of meat per day. Pigs are usually slaughtered in a separate works. A recently opened large works in Denmark slaughter about 1 million pigs per year producing about 65,000 tonnes of meat.

The major problem with the in-works treatment of carcasses is recontamination during handling and processing.

In laboratory situations recontamination can be controlled or prevented but this is more difficult in an industrial situation.

The high incidence of both Salmonella and Campylobacter on pork carcasses is a world-wide problem. On-line carcass irradiation would help provide a solution.

TREATMENT OF PACKAGED FRESH MEATS

By vacuum-packaging, the storage life of cuts of beef can be extended to 10-12 weeks. To achieve this the muscle pH must be less than 6.0 and the packaging film must have a low permeability to gases (< 100 ml of O_2/24h/atm measured at 25°C and 98% rh). This product forms the basis for a major export trade for Australia.

Vacuum-packaging extends storage life because the putrefactive spoilage bacteria are replaced by psychrotrophic lactic acid bacteria. These are non-pathogenic and non-putrefactive and when they eventually cause spoilage it is by souring (Egan, 1984).

Recent studies have shown that sterile beef muscle stored vacuum-packaged at 0°C still spoils slowly (storage life 14-18 weeks) because of the development of a changed flavour described as sour, acid, bitter and liver-like. This is probably caused by chemical changes resulting in part from enzyme activity in the stored muscle. Thus there appears to be little scope for further extension of the storage life of this product by use of irradiation.

Vacuum-packaging works well with beef because (at least in Australia) there is normally only a low incidence of high pH or dark-cutting meat in the premium muscles of the hind quarter, which are the ones usually packaged for export. If muscle pH is greater than about 6.0, Alteromonas spp. and Enterobacteriaceae can grow and contribute to spoilage which is then much more rapid.

High pH meat is much more common in pig and sheep carcasses. These meats which are also associated with increased fat content or fat cover, are commonly packaged as bone-in cuts or even whole carcasses, and this results in larger head space volumes and hence higher residual oxygen concentrations in the packs. These factors combine to give a shorter storage life than obtained with beef cuts (Table 1).

Table 1: Estimates of the maximum storage life of vacuum-packaged fresh meats at 0°C

		Muscle pH	Storage life (weeks)
Beef	Boneless cuts	5.4 - 5.8	10-12
Pork	Boneless cuts	5.4 - 5.8	6
	Boneless cuts	6.0 - 6.4	4-6
Lamb	Cuts (bone-in)	Variable	6-10*
	Carcasses	N/A+	6-8

* Little studied, varying estimates in literature.

\+ Not applicable

If the storage life of vacuum-packaged chilled pork and lamb can be extended by a low dose treatment (2-5 kGy) it may be possible to greatly increase international trade in these products and thus avoid freezing them.

Treatment of vacuum-packaged meats may enable them to be stored at a higher temperature of (say) 5°C rather than at 0°C and this would permit considerable savings in energy. Packaged meats are usually placed in cartons immediately after the packaging operation and treatment with ionising energy would be of the cartoned product which would simplify handling procedures.

The storage life of consumer cuts of meat for retail sale may be extended to two weeks at about 5°C by storage in modified gas atmospheres (carbon dioxide 20%, oxygen 80%). Low dose treatment may be useful with these products.

When fresh meats are minced or ground, the bacteria are distributed throughout the tissue and the rate of spoilage is rapid. The advantages of packaging and ionising energy treatment to improve the quality of packaged ground meats have recently been discussed (Maxcy, 1982; Niemand _et al._, 1983).

TREATMENT OF PROCESSED MEATS

The principles to be observed in treating processed meats and the problems likely to be encountered are generally similar to those with raw meats. Some processed meats certainly pose a particular problem in having an inadequate storage life.

Luncheon meats are commonly sold sliced and vacuum-packaged. They are cooked but then recontaminated during slicing following which the starting count may be 10^4 bacteria per g or even higher. Since the surface-to-volume ratio is comparatively high, bacterial spoilage may occur after only 2-3 weeks at about 5°C.

Recently, we have been examining the use of irradiation to extend the storage life of sliced vacuum-packaged corned beef. Table 2 shows the reduction in starting count, organoleptic changes in flavour and aroma and the storage life of this product following irradiation at different dose levels. Under commercial conditions the dose to be used will depend upon consumer acceptance. Corned beef is a relatively bland product and further studies using products with stronger flavours (e.g. smoked ham) are needed, since the irradiation induced changes may be less noticeable.

Table 2: Effect of treatment dose on microbial population, organoleptic properties and storage life of vacuum-packaged sliced corned beef.

Irradiation dose (kGy)	Reduction in starting count (log cycles)	Panel evaluation of flavour/aroma changes	Estimated storage life at 5°C (weeks)
0	-	-	2-3
1	1	Not significant	2-3
2.5-3.0	3	Significant-slight	5
4	5	Significant - slight/moderate	>6

SPECIAL APPLICATIONS

Special applications of ionising energy treatments in the processing of meats have been discussed recently by Dempster (1984). For example it can be used to prepare "commercially sterile" meat products which are storable without refrigeration. This has been achieved with beef by cooking, vacuum-packaging, freezing to about -40°C and irradiating at 50 kGy. In this process, cooking inactivates the enzymes and irradiating at low temperature greatly reduces the organoleptic changes.

CONCLUSION

The use of ionising energy treatment has the potential to greatly increase the storage life and to reduce the public health hazards associated with meats. As food irradiation becomes more common throughout the world, the opportunities to use it for the treatment of meats will increase. The problems associated with the treatment of meats (e.g. organoleptic changes) can be overcome particularly if the treatment is used in combination with appropriate packaging and storage conditions. Ionising energy treatment will create opportunities to produce new types of meat products. It has the potential to contribute to increasing the availability of meats, particularly processed meats, in areas of the world in which they are not now in adequate supply.

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LECTURE 17

IONISING ENERGY TREATMENT OF POULTRY

R. PROUDFORD

IONISING ENERGY TREATMENT OF POULTRY

R.W. Proudford

SUMMARY

Following FAO/IAEA/WHO approval in 1980 for the low dose treatment of foods by ionising radiation, considerable interest has been directed towards the possible use of this process in the poultry industry, particularly in terms of controlling Salmonellae.

To evaluate the suitability of this process, objectives relating to technical efficiency, economic feasibility, regulatory acceptability, need, marketability, and volume logistics need to be fulfilled. As a measure of the fulfillment of these objectives, quantifiable rather than qualitative criteria should be developed. Also, to facilitate the evaluation, a structured approach should be followed using Rawson's conceptual model.

The main food-borne pathogens associated with poultry in Australia are Salmonellae, *Campylobacter jejuni*, *Staphylococcus aureus* and *Clostridium perfringens*. The poultry industry claims that as a result of good manufacturing practice and low temperature storage, the Salmonellae problem has largely been contained, but not eliminated.

Work performed by Mulder (1983) confirmed that low dose treatment of poultry in oxygen impermeable pouches held at -18°C was effective in reducing the number of Salmonellae per carcass, from about 1,000 to 1. This is possible using a dose of 3.9 kGy, arrived at using the D_{10} for *S.panama* (the most resistent *Salmonellae* serotype) at -18°C.

As well as substantially reducing the population of Salmonellae on carcasses, a dose of about 4 kGy will also greatly extend the shelf life of the product by about 9 days, if held at about 1°C (the storage life of non-irradiated poultry at this temperature is about 8 days). This is achieved by destruction of spoilage organisms belongong to the genera *Pseudomonas*, *Acinatobacter* and *Flavobacterium*.

Problems associated with off-odours and off-flavours have been reduced significantly by low temperature storage (-18°C) and by the exclusion

of oxygen during irradiation.

The highly centralised structure of poultry processing, the high volume output, and the traditional problem with Salmonellae contamination make the industry a suitable potential candidate for ionising energy treatment of its products.

LECTURE 18

SPOILAGE OF SEAFOODS

S. THROWER

SPOILAGE OF SEAFOODS

by

S.J. THROWER

INTRODUCTION

The maintenance of high quality standards in catching, handling and processing fish presents great challenges to everyone involved in the seafood industry. Fishing is a hunting occupation and the seafood industry has less control over the condition, mode of death and transport of its raw material than is possible with farm products. The flesh of fish, because of its physical structure and chemical composition, is intrinsically highly perishable. Despite this, retail prices of fish are high and fish is no longer the cheap "penance" food of earlier times, but a much sought after delicacy. The seafood industry is faced with the challenge of providing the consumer with a product that retains fresh flavour, firm succulent texture, natural colour, and fresh aroma. To do this, a co-operative effort in quality control is needed from the vessel to the plate; everybody in the industry needs to be aware of the spoilage factors that affect fish quality and how these factors can be controlled.

From the time a fish is caught, physical, chemical and bacterial changes begin to occur. Many of these changes are inevitable but they can be controlled, to some extent, by appropriate handling and temperature control. Other changes are avoidable, and are the direct result of poor hygiene and bad handling practices. They can be eliminated by good layout, thorough sanitation, and careful handling. A clear understanding of what happens to a fish after it is caught is central to the implementation of effective quality assurance measures.

Rigor Mortis

When a fish dies, a series of physical changes begins to occur. The muscles go into a state of contraction as energy-rich compounds are "burnt up" by the uncontrolled metabolism of the animal. The body stiffens into the rigid condition known as rigor mortis. The flesh of fish in rigor is very "brittle", since the contracting blocks of muscle exert great tension on the delicate sheets of connective tissues that join the muscle blocks together and anchor the ends of muscles to the skin and the skeleton. Any physical abuse such as bending, throwing, kicking or crushing of fish in rigor will tear apart the connective tissue. Fishermen may be familiar with the feeling of "give" when a shark is hoisted by the tail, tearing the connective tissue sheets. This results in ragged, gaping fillets and poor freezing and cooking properties.

For many years it has been known that rigor mortis is associated with the breakdown of the energy compound adenosine triphosphate with the associated lowering of pH as organic acids are produced in the glycolytic cycle; lactic acid in fish and succinic acid in some shell fish. The onset and resolution of rigor are now known to be intimately linked to the ability of muscle proteins to bind calcium ions (Ca^{+2}). The control is lost when the lipoprotein membranes around the muscle fibres lose their ability to bind Ca^{+2} (Ebashi, 1974).

When the supply of high energy compounds is exhausted , the muscles relax, the acid dissipates, and rigor has been resolved. Two important factors should be remembered about rigor mortis:

Fish in rigor is very delicate and should be carefully handled to avoid physical damage.

Rigor is caused by biochemical processes and reducing the temperature of the fish will prolong rigor, reduce the strength of muscle contractions, stabilize the connective tissues, and thus protect the fish from damage.

Autolysis

The flesh of fish may also be adversely affected by its own enzymes in a process known as autolysis. The jaws and teeth of most fish are designed to seize and tear their prey rather than chew it. Food is swallowed in large chunks and digested by powerful enzymes in the digestive tract. After death, these enzymes leak out into the body cavity and begin to attack the body lining and the flesh (Gildberg, 1982). This can lead to condition known as "belly burn" seen in fish such as flathead (*Platycephalus sp.*). This process is often exacerbated if the gut wall is split by physical abuse such as careless use of the gaff, overpacking of fish bins, or a misplaced boot.

Another type of autolysis is caused by tiny 'lethal bags' of enzymes in the flesh itself which rupture after death releasing their contents into the flesh to degrade muscle proteins and lipids.

Autolysis can be controlled by careful handling to avoid damage to the guts, clean thorough gutting, and disposal of offal in such a way as to avoid contamination of the catch. Being a biochemical process, the rate of autolysis can be reduced by prompt, effective chilling and maintenance of low temperatures.

Bacterial Action

The next class of spoilage, and the one which will be considered in greatest detail, is bacterial spoilage. The emphasis given to this topic is a reflection of the fact that this form of spoilage has been studied in greater detail than the others. In the author's opinion, based on years of observations made at sea and ashore, physical damage to fish during catching, sorting and loading operations followed by inadequate temperature control during storage and transport causes most of the deterioration in seafoods. Autolysis and bacterial action are the agents which bring about that deterioration.

In a living fish bacteria are confined to "external" surfaces the skin, gills and gut contents (Table 1). The flesh of the fish is sterile and bacterial growth is prevented by the animal's own immune system. After death of the fish, the immune system ceases to function and bacterial growth is no longer held in check. For whole fish held at chill temperatures the diffusion of compounds into the fish from bacteria growing on the skin, gills and in the guts produces off flavours and odours in the flesh which lead to eventual rejection of the product. If fish is stored above 8°C however, bacteria are more mobile and invade the flesh via collagen fibres, even while the numbers on the skin are still relatively low (Shewan and Murray, 1976).

Bacterial spoilage can be reduced in several ways. Hygienic handling practices will minimise post-catch contamination; thorough washing will reduce the number of bacteria on the surface of the fish, and prompt reduction of temperature will lower the rate of bacterial growth.

Hygiene on board

Anyone who has worked in fish netting operations such as trawling or inshore meshnetting will have seen the large quantities of weed, mud and other debris that is hauled in with the fish in the net. Prompt sorting and washing of the fish is essential to segregate edible species in a clean part of the boat. The maintenance of good hygiene is not easy on fishing vessels. Deck surfaces need to be rough to ensure firm footing in rough weather and bare wood is often favoured.

Fishermen see boats primarily as catching platforms, and space and labour is often allocated on the basis of efficient shooting and recovery of gear at the expense of proper washing, sorting and stowage facilities. Two factors working in favour of effective hygiene practices are the availability of copious supplies of clean seawater from the deckhose, and the exposure of many of the surfaces to the sterilising effects of direct sunlight. The latter advantage is often lost on larger vessels which are fitted with shelter decks to protect the crew from weather, and fish holds below decks which are usually dark, damp areas often containing stagnant bilge water. In general, if impervious materials are used wherever possible for surfaces coming in contact with fish, if slime, offal, scales and blood are scrubbed off before they dry on the surface, and if good sanitation practices are followed, it is possible to maintain good conditions of hygiene on even the smallest of boats (Thrower, 1984). Unloading and road transport systems, especially those using fish pumps and conveyors require specialised cleaning and sanitation (Liston, 1980).

Cleaning Fish

Bacterial numbers may be reduced in a number of ways. Thorough washing of fish in fresh seawater will remove most of the mud etc. that adheres to the fish. Prompt, effective heading and gutting can be used to remove the gills and intestines, two major sources of bacteria.

Chilled Storage

Chilling and stowage of fish is usually combined into one operation. The method of chilled stowage used will depend on the size of the haul, small catches are often iced while larger catches may be more effectively chilled by refrigerated seawater (RSW) or seawater chilled with ice (CSW). Methods of effective chilling of fish have been described in detail by Thrower (1982) and Graham and Sykes (1982). The key factors to watch in chilling fish are the use of a chilling medium which has a high capacity to absorb heat, and good contact between the medium and the fish. Once the catch has been chilled it is necessary to maintain low temperature. This is done by effective use of insulation combined with the use of ice or mechanical refrigeration to counter ingress of heat from external sources such as the deck, engine room bulkheads, and propeller shaft housing.

UNLOADING AND TRANSPORT

On arrival at the wharf, the catch must be unloaded and transported to the factory or market with a minimum of delay. Good standards of hygiene must be followed. Sufficient ice should be added to ensure that low temperatures are maintained.

During transport fish should be held in clean impervious containers and covered to protect them from sunlight, wind, flies, dust and other sources of contamination. Delays in transport must be kept to a minimum.

PROCESSING

At the factory, the fish must be unloaded promptly and kept cold prior to processing. Some rise in temperature is inevitable during processing, but this can be minimised by efficient programming of production. Processing establishments should follow a well developed programme of cleaning and sanitation (Thrower 1980) to ensure that contamination of product does not occur. It is of benefit for quality control staff to conduct a careful survey fairly often to ensure that good hygienic practices are being followed and that delays allowing unacceptable rises in temperature have not been allowed to develop on the production line.

PRESERVATION OF SEAFOODS

A number of options are available to the seafood industry to protect its products from deterioration.

Low temperature storage

Maintenance of low temperature is one of the most frequently used methods of regulating growth of spoilage microorganims in seafood products. For most practical purposes, frozen storage of food will prevent bacterial spoilage although chemical, biochemical and physical changes will still occur. It is in the chill temperature range (-2 to +4°C) that much of the work on bacterial spoilage of seafood has been done. This is probably because ice has traditionally been used as the main chilling system on fishing boats.

Bacteria are often classified by the three cardinal temperatures which control their growth. The system of classification specified by Morita (1975) is shown in Table 2 and will be followed in this paper.

Ratkowsky *et al* (1982) used the linear relationship

$$\surd r=b(T-T_0)$$

to relate rate of growth of bacteria (r) to temperature (T) where (b) is the gradient of the line and (T_0), the intercept on the temperature axis, is the theoretical minimum temperature for growth. This minimum temperature is 'theoretical' because as the temperature reaches 273°K, ice forms and the lowering of water activity (A_w) rather than temperature effects prevents bacterial growth at temperatures between 273°K and T_0. For example the Aw of frozen food is 0.953 at 268°K and 0.907 at 263°K (Christian 1980). The square root relationship can also be used to describe nucleotide breakdown (T_0 = 265°K) and aerobic spoilage of proteinaceous foods at chill temperatures. The T_0 value for the latter is similar to the T_0 for for *Pseudomonads* sp. (263-265°K) which are the predominant species that survive under chilled aerobic conditions. *Alteromanas* sp., the predominant species in fish spoilage, have a T_0 of 263° to 268°K whilst *Actinetobacter* sp. isolated from tropical prawns, have a T_0 of 276 to 278°K (Ratkowsky *et al* 1982).

There has been some controversy over whether the shelf life of tropical species can be extended to a greater extent than that of temperate water species by chilled storage, and this topic has been reviewed in depth by Lima dos Santos (1981). He found that it was difficult to distinguish between temperate and tropical waters. For example the seas off 'tropical' Angola might fall to 15°C whilst the waters of Loch Lomond in Scotland reach 20°C in summer. In a study of published results from over 200 storage trials, the author was unable to categorically state that tropical species have a longer shelf life in iced storage than colder water species

Heat treatment

For many years seafoods have been preserved by thermal processing and storage in hermetically sealed cans. This process eliminates both autolytic and bacterial spoilage by denaturing enzymes and killing bacteria. More recently retortable plastic pouches (Lampi 1977) have been used to pack such products as seasoned abalone. Such processing requires a considerable amount of preparation and energy, but eliminates the need for refrigeration. The nature of the seafood is of course fundamentally changed; it is now a cooked product.

Drying

Man has known how to preserve fish by dehydration for thousands of years. This process relies on reducing the water available for the growth of spoilage microorganisms, usually measured as the relative humidity or water activity (A_w). The relationship between A_w and moisture content is shown in Fig 1. Several methods are used to lower the A_w. The operation of these methods can be explained by considering the method of calculating the A_w of a solution:

$$A_w = \frac{\text{Moles of water}}{\text{Moles of water + moles of solute}}$$

So, for example the A_w of a 1 molar glucose solution (198 g of glucose in 1000 g of water) may by calculated thus:

$$A_w = \frac{55.5}{55.5 + 1} = 0.98$$

It is obvious from this calculation that A_w can be reduced either by reduction of water or addition of solute. In practice, both these methods are used.

Air Drying

Fish are traditionally dried by leaving them exposed to the effects of sun and wind. Such a method is of course very vulnerable to infestation by insects and to the vagaries of weather. The products of such drying techniques are often unattractive in appearance and strongly flavoured due to enzymic and non-enzymic browning and may also suffer from rancidity. Dramatic improvements in the process have resulted from the introduction of solar driers which employ better convection and protect the product from rain and insects (Doe *et al.*, 1977). The use of mechanical drying kilns has enabled the processor to operate in most weather conditions and to better control rates of drying.

Salt Curing

Salt curing involves the removal of water from the flesh into a strong salt solution and absorption of salt into the flesh. The product is either buried in salt or immersed in strong salt solution, the body fluids are drawn out, and salt is progressively taken up. Growth of microorganisms is inhibited both by the low A_w and the high salt content. (Table 3) Problems are sometimes encountered due to uneven distribution of moisture in the product leading to isolated areas of high A_w. In humid climates the product will reabsorb moisture from the air, raising the A_w to permit the growth of yeasts and molds. Dried products need to be soaked in water to reconstitute and remove excess salt, so they are inconvenient to prepare.

Smoking

In earlier times, smoking was combined with heavy salting and drying to preserve fish. The chemicals in the smoke, mostly phenols, sterilised the surface of the product, while the salt and low A_w gave most of the preservative effect. Today smoking is used to impart a characteristic flavour rather than to preserve the fish. The product is maintained at quite a high A_w and the salt content is restricted to 2-3%; refrigeration is used to preserve the fish. Two types of smoked products are produced, hot smoked products which are cooked by smoking at temperatures above 70°C and cold smoked products which are smoked at temperatures below 30°C. Hot smoked products are thus pasteurised whilst cold smoked products are not.

Fermentation

Fermentation is also an ancient way of preserving fish. Fermented seafoods reached a peak of popularity in Graeco-Roman times but waned with the decline in Roman power (Badam, 1854). In Western society fermentation of seafoods is restricted to delicacies such as Scandanavian 'tidbits' and French anchovies. Today fermented seafoods are of dietary significance only in Asia as a cheap method of preservation in a hot humid climate. In Vietnam where daily intake of fish is 40g/head, 7.5% of nitrogen intake comes from 'nuoc-nam', a fermented fish sauce. (Amano, 1962) Fish are partially cured by the addition of 13% salt, which prevents gross bacterial spoilage whilst allowing autolysis by digestive and catheptic enzymes to proceed. Some restricted growth of microorganisms does occur. Sometimes a carbohydrate source is added to lower the pH by forming organic acids as fermentation proceeds. The mixture may be stored anaerobically for periods ranging from months to years with the sauce, which contains peptides, amino acids and creatine as well as some volatile bases, being drawn off as required.

Modified Atmosphere Storage

In recent times there has been an increased interest in using modified atmosphere storage (MAS) to reduce the rate of spoilage of seafoods. Current research was reviewed by Statham (1984) and is briefly summarised here.

A number of gases and gas mixtures have been used but only two compounds, sulphur dioxide and carbon dioxide have found acceptance. Sulphur dioxide is used to prevent 'black spot' (enzymatic melanosis) in crustacea (Ruello and Beilby, 1976) and 'blue spot' (haemocyanin staining) in canned abalone.

The preservative effect of CO_2 on flesh foods was first demonstrated by Kolbe in 1882 and since then has been shown to increase chilled storage life by 50-100% by reducing the rate of bacterial spoilage.

Although the mechanism by which CO_2 inhibits bacterial growth is still not clear, it is known that the gas readily dissolves in the water in the seafood, especially at chill temperatures. This causes a decrease in pH, the extent of which depends on such factors as the buffering capacity of the flesh. The effect of CO_2 on bacterial spoilage is threefold it increases the lag phase of growth, reduces the rate of growth, and has a selective bactericidal effect on certain types of bacteria.

This results in the development of a flora that is dominated by lactic acid bacteria rather than the *Alteromonas/Pseudomonas* sp. commonly encountered in chilled aerobic storage, and the production of chemical spoilage indicators such as trimethylamine is reduced. Storage in CO_2 enriched atmospheres does however result in some deleterious effects. The flesh may develop a greyish tinge necessitating the use of antioxidants. Excessive drip loss, probably caused by a loss of water-holding capacity as the pH falls may necessitate the use of high levels of polyphosphates. For some species deterioration in organoleptic properties, odour, flavour and texture have been reported.

The use of modified atmosphere storage may be envisaged at three levels; bulk containerised transport; a master pack for shipping permeable over wrap packs to supermarkets, and impermeable consumer packs using MAS.

Sorbic acid has been used for some years to increase the shelf life of some seafood products such as fish sausage (Wada *et al.*, 1976) and salted fish (Doesburg *et al.*, 1969). In more recent times potassium sorbate has been used in combination with vacuum packaging to increase the chilled storage life of seafoods. For example the storage life of Tasmanian scallops held at 4°C was extended from five to eleven days by treatment with sorbate (1g/kg) and up to twenty one days by a combination of sorbate and vacuum packaging (Statham, 1983). It appears that the growth of *Pseudomonads* is inhibited by the anaerobic conditions whilst that of *Vibrio* sp. a predominant cause of scallop spoilage, is prevented by sorbate.

INTEGRATED APPROACH TO SEAFOOD PRESERVATION.

In commercial practice it is rarely possible to obtain ideal application of any one form of preservation. For example, refrigeration plants do not run perfectly all the time, drying of product is not perfectly uniform and delays often occur in processing systems. For this reason it is often useful to employ more than one technique. This was shown above in the combination of sorbate with vacuum packaging and refrigeration with smoking. Doe (1985) describes an integrated program of research undertaken by Filipino, Indonesian and Australian scientists to quantify the combination of the effects of lowered water activity and temperature on the spoilage rate of fresh and dried fish. The method will be summarised here.

The square root of the rate of growth of a spoilage organism is plotted in three dimensions against two parameters in this case water activity and temperature. The three dimensional plots for the likely spoilage organisms are then combined to form a 'spoilage envelope' which combines all the growth characteristics of the likely spoilage organisms. This plot can then be used to give a contour map which relates temperature and water activity to give a partial spoilage index. It is then possible to evaluate a drying process by multiplying the partial spoilage index for a given temperature and water activity by the exposure time to those conditions and summing these to give a spoilage index. If the spoilage index for a given process reaches 100 the fish would be spoiled and the process used would be a failure. It would be possible to use a similar procedure to include other parameters such as pH. Extension of this concept should generate a library of partial spoilage indices to enable the processor to design an optimal process combining a number of different technologies.

FOOTNOTE

The author has not attempted to discuss the use of radiation in preventing spoilage of seafood. Other more expert lecturers will pursue this topic. From reading the literature it would appear that radurization could fit in nicely with the other means of preservation to reduce the bacterial load on seafood prior to the application of other techniques. In this context it would be prudent to recommend that radiation be employed as soon as practicable after the catch is landed.

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Table 1. Distribution of bacteria on a newly caught fish[1]

Organ	Bacterial Numbers
muscle	sterile
gills	$10^2 - 10^5$ g^{-1}
integument	$10^3 - 10^9$ cm^{-2}
intestines[2]	$10^3 - 10^9$ g^{-1}

[1] Source Shewan (1976)

[2] for 'feedy' fish

Table 2. Classification of Bacteria According to Cardinal Temperatures

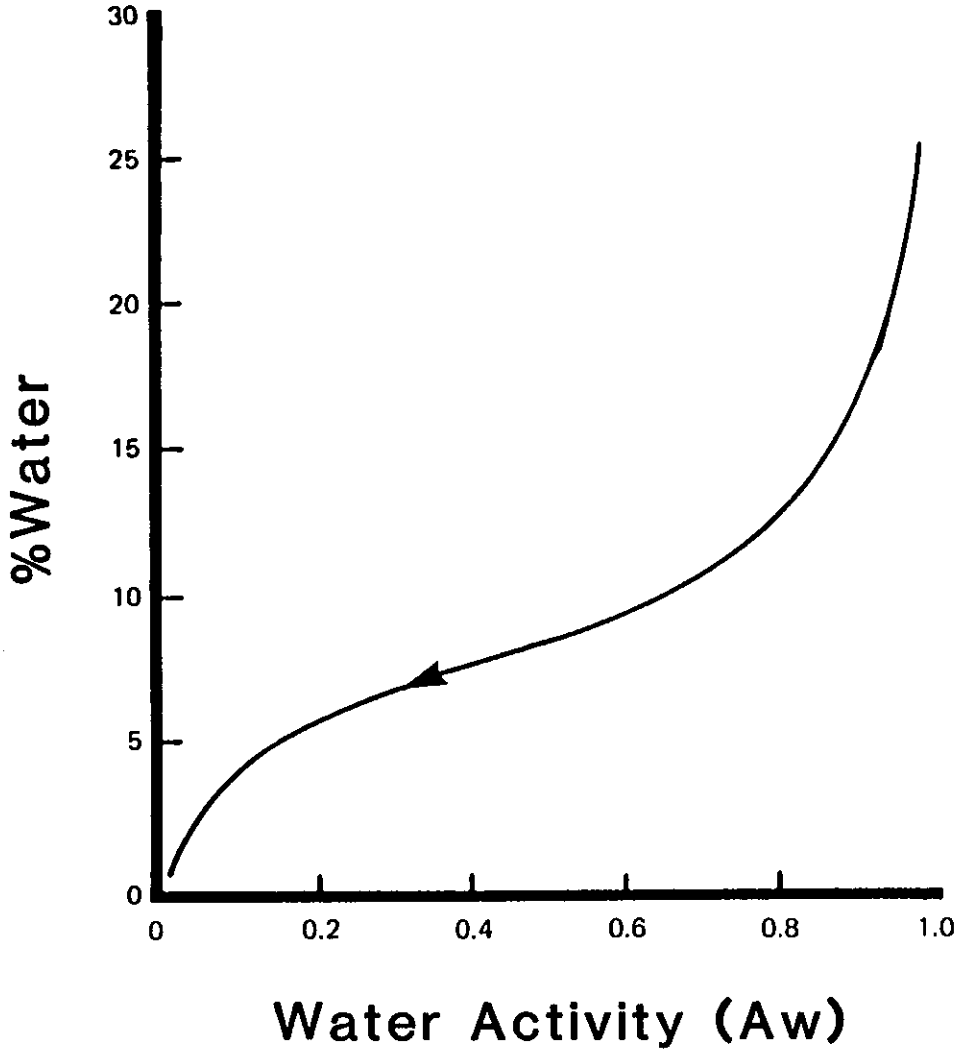
Group	Temperatures °C		
	Minimum	Maximum	Optimum
Thermophiles	40–45	55–75	60–90
Mesophiles	4–15	35–45	35–75
Psychrotrophs	−5–+5	25–30	30–35
Psychrophiles	−5–+5	12–15	15–20

Table 3. Water Activity values below which growth of Microorganisms does not occur.

Organism	Water activity (A_w)
Bacteria	0.9
Yeasts	0.88
Molds	0.80
Halophilic Bacteria	0.75
Xerophilic Bacteria	0.65
Osmophilic Yeasts	0.61

Source: Thrower and James (1974)

Fig. 1 Sorption Isotherm



LECTURE 19

PUBLIC HEALTH PROBLEMS ASSOCIATED WITH FISHERY PRODUCTS

M. EYLES

PUBLIC HEALTH PROBLEMS ASSOCIATED WITH FISHERY PRODUCTS

M.J. Eyles

CSIRO Division of Food Research, P.O. Box 52, North Ryde,
NSW 2113.

In those countries which maintain useful records of food-borne disease, fishery products account for a significant proportion of the outbreaks reported. The proportion varies from one country to another, depending on climate, dietary customs and other social differences. In the USA about 11% (233) of the food-borne disease outbreaks reported between 1970 and 1978 were transmitted by fish, shellfish or marine crustacean products (Bryan 1980). In Japan, where raw seafood is popular, about 70% of the cases of food poisoning that occur in summer months are caused by a single bacterial pathogen derived from fishery products, *Vibrio parahaemolyticus* (Joseph et al. 1982).

Many substances or organisms hazardous to health can be ingested with fishery products, including toxic chemicals (e.g. mercury, pesticides), toxins produced by certain fish (e.g. puffer fish), and parasites (e.g. *Anisakis*). However, diseases caused by microorganisms, especially bacteria, constitute the largest proportion of fish and shellfish-borne diseases. Partly because of increasing trade in fishery products and the trading difficulties which can be caused by microbial contamination, more international attention has been focused on questions of hygiene, public health and microbiological specifications in recent years. This discussion will concentrate on some of the more significant illnesses caused by microorganisms that can be transmitted by fishery products.

Fish-borne and shellfish-borne diseases are frequently divided into three categories on the basis of the major source of the responsible agent (Bryan 1980): 1. agents naturally present in aquatic environments, 2. agents derived from pollution of aquatic environments, 3. agents derived from workers, equipment or the environment of food handling, processing or service establishments.

AGENTS NATIVE TO AQUATIC ENVIRONMENTS

Clostridium botulinum

Toxins produced by the various types of the bacterium Clostridium botulinum cause botulism, the well-known neuroparalytic disease affecting humans and animals. Food-borne botulism, which results from the ingestion of food in which C. botulinum has been allowed to grow and produce toxin, is the form of the disease which is of concern to the food industry. Although modern medical techniques have brought about a marked decline in the fatality rate in outbreaks of botulism, it remains a very serious, potentially fatal disease. Because of the serious nature of botulism, its prevention is one of the most important considerations in assuring the microbiological safety of a wide range of foods, including fishery products. Many procedures used for the processing and storage of fishery products, in common with other foods, are designed specifically to prevent the growth of C. botulinum. Fortunately, food-borne botulism is now a relatively rare disease, but history has shown repeatedly that food processors who use improper procedures and cause an outbreak of botulism face severe, often ruinous, economic problems. These problems are frequently not restricted to the responsible processor, but affect a wider sector of the food industry.

The species C. botulinum includes a heterogeneous collection of anaerobic, spore-forming bacteria which have in common the production of one of the characteristic neurotoxins (Hobbs 1981). The species is divided into types A to G on the basis of the antigenic specificity of the toxins. Types A, B, E, F and G cause human botulism. These types are divided into two groups, proteolytic (A,B,F) and non-proteolytic (B,E,F) on the basis of physiological characteristics. The non-proteolytic types are of particular interest in the present context because of their low minimum growth temperatures (3-4°). Proteolytic types will not grow below 10-15°C. *C. botulinum* has been shown to grow well in a variety of foods. Toxin production usually accompanies growth. The toxins are proteins which are heat labile and readily destroyed by many normal cooking processes.

For food-borne botulism to occur, the following events must coincide (Eklund 1982). 1. A food must become contaminated with *C. botulinum*, usually from the environment. 2. The processing treatment must be inadequate to inactivate the *C. botulinum* present, or the product must be recontaminated after processing. 3. The food must be held under conditions which allow growth and toxin production by *C. botulinum*. 4. The toxic food must be acceptable to the consumer and must be eaten without cooking or after insufficient heating to inactivate the toxin. The non-proteolytic types in particular have little effect on the odour or flavour of food.

C. botulinum is widely distributed in soil, aquatic environments and other habitats. It is a natural contaminant of fish, including shellfish, and may be found in both ocean and freshwater fish at the time of catching or harvest (Hobbs 1976). All *C. botulinum* types may be present in aquatic environments, however type E is the type which has been isolated from aquatic sources most frequently and is the type most commonly implicated in outbreaks of botulism caused by fishery products. The number of *C. botulinum* spores or vegetative cells present in freshly harvested fish is believed to be low, no more than a few per gram of flesh, although few studies have been quantitative. Thus, there is usually no risk unless the food is held under conditions which allow growth of *C. botulinum*.

The incidence of *C. botulinum* and the types present in aquatic environments depend on a variety of ecological factors and vary markedly in different geographical regions (Hobbs 1981). The cold-tolerant (psychrotrophic) type E is present in a high proportion of samples collected from some cooler areas, such as parts of the North Sea, the US Great Lakes and around the Northern Japanese Islands, but is found infrequently in tropical and sub-tropical waters. Tanasugarn (1979) examined over 2000 fish samples from the Gulf of Thailand and found type E in only 5 samples and type D in 10 samples. *C. botulinum* was found in 2.4% of 3,433 sediment and seafood samples from Indonesian waters (Suhadi et al. 1981). Types A, B, C, D and F, but not type E, were detected. Although the risk that fishery products will cause botulism obviously varies markedly from place to place, it can never be assumed that *C. botulinum* spores are not present in raw fishery products.

Because many raw foods are likely to be contaminated by *C. botulinum*, the food industry uses a variety of techniques to prevent food-borne botulism. These vary with the product, but fall into two broad categories.

1. The complete destruction of the spores, usually by heating, accompanied by measures to prevent recontamination of the product (e.g. canning of low-acid foods).
2. Inhibition of the growth of *C. botulinum* by physical or chemical means or a combination of these (e.g.

salting, smoking etc.).

The historical record shows that fresh or frozen fishery products are low risk foods with respect to botulism. Two important safety factors act to prevent such products from causing botulism. The first of these is the activity of the microorganisms which cause spoilage. As mentioned earlier, some types of *C. botulinum* can grow and produce toxin at refrigeration temperatures. However, toxin production in unprocessed fish at temperatures below 10°C is usually so slow that spoilage is apparent to the consumer and the fish is rejected before detectable amounts of toxin are produced. In general, there is believed to be an increased safety margin between spoilage and toxin production as temperatures are reduced below 10°C. The second safety factor is cooking, since normal cooking of raw fish causes a substantial degree of inactivation of botulinum toxins. Nearly all of the outbreaks in which fishery products have implicated have been due to preserved, i.e. smoked, salted, canned or fermented products, usually eaten without further cooking.

Clearly, the risk of botulism can be increased by preservation processes which selectively destroy or inhibit the spoilage bacteria while having little lethal effect on *C. botulinum* spores and possibly enhancing future growth of *C. botulinum*. Treatments such as irradiation, smoking or modified atmosphere storage eliminate or modify the type of spoilage typical to raw products, extend the refrigerated shelf-life of the product, and interfere with the first of the safety factors metioned above (Eklund 1982). History and experimental data warn that botulism outbreaks are likely to occur if technologies of this type are introduced or modified without extreme caution.

Experiments performed using fish artificially inoculated with *C. botulinum* spores have shown that the radurization process increases the potential hazard from *C. botulinum* if irradiation doses over 100 Krad (1kGy) are employed and products are stored above 3.3°C (Eklund 1982). Toxin production in advance of spoilage has been demonstrated in several species of fish from temperate waters. The degree to which the hazard is increased varies with many factors, including the type of *C. botulinum*, the degree of initial contamination, the species of fish, the packaging and storage techniques used, the irradiation dose and so on.

There has been considerable debate over whether this increased hazard is sufficient to preclude the use of radurization for extension of the storage life of fresh fish. If the process is carried out only at plants adhering rigorously to good irradiation practices, using high quality raw materials, and the irradiated product is handled and stored appropriately, especially with respect to temperature, there is no increased risk of botulism associated with the process (Giddings 1984). Certainly there is no hazard if irradiated fish are held at or below 3°C. However, the integrity of the cold chain cannot be assured, especially at the retail and domestic levels of distribution and storage. Similarly, consumers cannot always be relied upon to use sensible cooking procedures. A decision on whether radurization of fishery products creates an unacceptable botulism hazard will vary with the circumstances surrounding each application. The process may well be acceptable in many situations, especially in regions where psychrotrophic strains of *C. botulinum* are uncommon.

Vibrio parahaemolyticus

Vibrio parahaemolyticus was first isolated from cases of gastroenteritis in Japan in the 1950's. Since then it has become widely recognised as a food-borne enteric pathogen, with reports of infection coming from all over the world, including many Asian nations. Diarrhoea is the main clinical sign of infection. The incubation period may be between a few hours and one or two days. The illness usually subsides within a few days, but in a proportion of cases persists for a week or more. Some victims can be quite severely affected. The illness caused by V. parahaemolyticus and the characteristics and ecology of the organism have been discussed in detail in several recent reviews (Blake et al. 1980, Joseph et al. 1982, Sakazaki 1979).

V. parahaemolyticus infections of man usually occur as a result of the consumption of contaminated and incorrectly handled fishery products. Some outbreaks caused by commercially prepared fishery products have been very large, involving hundreds of cases. Other types of food which have become contaminated from seafood or aquatic sources have also acted as a vehicle for the illness. The organism is a part of the normal microflora of estuarine and coastal waters throughout the world. It is found in water, sediment, plankton, fish and shellfish. The level of contamination usually follows a seasonal cycle. In cooler countries the highest counts are recorded in summer and autumn and the lowest counts in winter. In tropical countries the seasonal cycle has been correlated with rainy and dry seasons. V. parahaemolyticus is found infrequently in freshwater or the open ocean.

Since it is impossible to prevent the presence of V. parahaemolyticus on raw fish and shellfish, various measures must be taken by those who handle and process fishery products to prevent outbreaks of food-borne illness. Fortunately, the number of V. parahaemolyticus cells present in freshly harvested animals is usually well below the large number required to cause illness. In addition, the organism is readily destroyed by cooking. Therefore, the most important means of controlling infection of man is the use of appropriate hygienic procedures to prevent growth of the organism in seafoods and to prevent recontamination of cooked foods from raw seafoods. Refrigeration or freezing are the most important methods of preventing growth of V. parahaemolyticus. Growth ceases at about 9-10°C and below. At higher temperatures, particularly between about 20 and 40°C, it grows very rapidly in suitable foods and can reach an infective dose within a few hours. Cross-contamination between raw fish or shellfish and cooked foods must be avoided by good sanitation in food handling establishments and strict separation of raw and cooked products. Cooling, rinsing or thawing of cooked products with sea water is also hazardous.

The incidence and pattern of infection with V. parahaemolyticus in different parts of the world reflects the ecology of the microorganism and national dietary habits (Joseph et al. 1982). In Japan, 24% of many thousands of cases of food poisoning reported in a large survey were attributed to V. parahaemolyticus (Blake et al. 1980). Most of the cases in Japan occur in the warmer months, when the level of contamination of seafood with V. parahaemolyticus is highest. The high incidence of the illness in Japan is due to the national preference for raw fish and shellfish (Sakazaki 1979). In countries like the USA, V. parahaemolyticus infections are much less frequent. Infection is most often caused by cooked fishery products, especially shellfish such as crab, shrimp and lobster, which have been improperly cooked or recontaminated after cooking, then held at temperatures allowing growth of V. parahaemolyticus (Joseph et al. 1982). Most outbreaks in the USA occur during the warmer months. In Indonesia the illness occurs throughout the year, probably because the year-round tropical climate provides good conditions for growth of *V. parahaemolyticus*. In a number of Asian countries, for example Thailand and the Philippines, *V. parahaemolyticus* appears to be a more common cause of gastroenteritis than *Salmonella* or *Shigella* (Sakazaki 1979).

Various other members of the genus *Vibrio* that are native to aquatic environments also appear to cause human illness when ingested with food, especially fishery products. Our understanding of the ecology and pathogenicity of these organisms is far from complete at present. *V. cholerae*, for example, is a part of the normal microflora in brackish surface waters. Gastrointestinal illness caused by *V. cholerae* has been associated with the consumption of raw seafoods and other foods. *V. cholerae* is well known to most people, since the species includes the agent of pandemic cholera. Infections with *V. vulnificus* have been attributed to consumption of raw seafoods, especially oysters. *V. vulnificus* is not a common pathogen but can be a particularly dangerous one. In persons with pre-existing illnesses (e.g. liver disease) the infection may result in a septicaemia which has been fatal in a number of cases. *V. vulnificus* appears to be relatively common in the estuarine and coastal environments that have been studied. These and other potentially pathogenic vibrios have been discussed in detail in recent reviews (Blake et al. 1980, Blake 1983, Desmarchelier 1984, Joseph et al. 1982).

Scombrotoxin poisoning

Scombrotoxin poisoning is caused by the consumption of scombroid fish (tuna, bonito, mackerel, saury, etc.) in which certain bacteria have grown (Arnold & Brown 1978).

These fish contain large amounts of the amino acid histidine in their flesh. Various bacteria can rapidly convert the histidine to histamine if the fish is stored at elevated temperatures, especially above 15°C. Toxic fish usually contain quite high levels of histamine and the clinical signs of the illness are similar to those of histamine poisoning (flushing of face and neck, headache, palpitations, dizziness, itching, etc.), although precisely which compound or group of compounds is involved in causing the illness is unclear. The illness has been observed in Japan, the Pacific islands, Indonesia, Europe, the USA and elsewhere. Both fresh and canned fish have been implicated. Scombrotoxin poisoning can be prevented by rapidly chilling freshly-caught susceptible fish and maintaining their temperature below 7°C.

Algal toxins

Certain marine micro-algae produce toxins that can cause illness in man if ingested in sufficient quantities. Ciguatera poisoning is a significant public health problem in some areas of the tropics and subtropics in the Pacific area. It is believed that the toxin responsible for ciguatera is produced by certain micro-algae and then transferred through the food chain until it reaches concentrations hazardous for man in larger carnivorous fish. Poisoning may be caused by a large number of species of fish associated with reefs and islands. The symptoms of the poisoning include nausea, vomiting, diarrhoea, sensory disturbances and various other manifestations. Death may occur in severe cases. Control of ciguatera poisoning is difficult. The occurrence of the poisoning is sporadic and unpredictable, depending on the levels of the toxic algae in the water. The toxin is not destroyed by cooking, drying or salting. Control is only achieved by preventing the marketing of susceptible fish (Bryan 1980, Schantz 1973).

Many species of shellfish may also become poisonous through feeding on toxic marine algae. Paralytic shellfish poisoning, often associated with "red tides", is a well known example. Discussion of these toxins is beyond the scope of this presentation. Control of the illnesses caused by these toxins is usually achieved by preventing the harvesting of shellfish at times when the toxic algae are present in the water in high concentrations. Shellfish poisonings have been discussed by Bryan (1980) and Schantz (1973).

AGENTS DERIVED FROM POLLUTION OF AQUATIC HABITATS

Persons suffering from a variety of enteric infections excrete pathogenic microorganisms in their faeces in vast numbers. Thus, pollution of rivers, lakes and coastal waters by human wastes can lead to the contamination of aquatic animals harvested for food with a wide range of pathogenic microorganismms. Pathogens are frequently introduced into watercourses or coastal waters by the discharge of treated or untreated sewage and by runoff from the land during rain. Although sewage treatment processes reduce pathogen concentrations in domestic sewage by varying degrees, very few of the processes in current use produce pathogen-free effluent. Agricultural wastes can also be a source of hazardous microorganisms, for example *Salmonella* species. Many outbreaks of hepatitis A, typhoid fever, cholera and viral or bacterial gastroenteritis, some involving hundreds of cases, have been attributed to the consumption of fish or shellfish from polluted waters (Bryan 1977, 1980, Eyles 1983).

Several factors have made shellfish, especially bivalves, the major source of problems of this nature. Shellfish are frequently cultivated in or harvested from estuarine or coastal waters subject to pollution. Bivalves such as oysters, mussels or clams collect their food by filtration of large volumes of water, so that the contents of the bivalve digestive tract closely reflect the material suspended in the water. Bivalves may accumulate human pathogens to concentrations well above those in the surrounding water. This problem is exacerbated by the common custom of eating bivalves raw. Even when they are cooked, the cooking procedures are often too mild to inactivate all the pathogens that might be present. Cooked bivalves have transmitted both hepatitis A and gastroenteritis.

Mis-handling of food after harvest is not necessarily required for disease transmission to occur by this route. The enteric viruses, such as those which cause hepatitis and gastroenteritis, do not multiply outside their human host. The dose of these agents necessary to initiate an infection is very small and the contamination acquired initially from polluted water is sufficient to cause disease. Some of the bacterial pathogens mentioned above (e.g. Salmonella, cholera vibrios) usually have a much larger infective dose and contaminated fishery products need to be subjected to temperature abuse between harvest and consumption, thereby allowing growth of the pathogen, for disease to occur in most cases.

Control of disease transmission by this route can be achieved by harvesting only from waters which are not unacceptably polluted or by subjecting shellfish or fish harvested from doubtful waters to a process that will inactivate or remove pathogens (e.g. effective heat treatment). Many countries have established procedures for controlling the quality of waters from which bivalves are harvested (Bryan 1980, Wood 1976). These procedures involve sanitary surveys of waterways to identify sources of pollution, followed by classification of areas into various categories of acceptability. These surveys should be supported by continued monitoring of the bacteriological quality of water and shellfish.

Purification is a process sometimes used to minimise contamination of bivalves. Human pathogens derived from pollution are believed to be associated transiently with bivalves. Thus, in several parts of the world, live shellfish are held in unpolluted water for a short time before marketing to allow any pathogens present to be excreted by the animals. The purification process is referred to as depuration if carried out in man-made tanks of water, or relaying if an unpolluted natural waterway is used. The process does not remove some pathogens (e.g. *V. parahaemolyticus*) that are native to aquatic environments (Eyles & Davey 1984) and its ability to remove viruses is doubtful.

AGENTS DERIVED FROM CONTAMINATION AFTER HARVEST OR CATCHING

Fish or shellfish may become contaminated with one or more of several groups of pathogenic microorganisms during processing, storage, distribution and preparation for consumption. Pathogens which cause some serious diseases, such as typhoid fever, hepatitis and cholera, can be introduced to fishery products by infected workers or polluted water in food processing or preparation establishments. Such contamination is not acceptable and, fortunately, is not common.

Fishery products become contaminated much more frequently with bacteria capable of causing food poisoning. Bacterial food poisoning is the most common and probably best known food-borne disease. It is characterised by a sudden onset of gastro-intestinal symptoms, such as vomiting, nausea, diarrhoea and stomach cramps, usually within a day or two of eating contaminated food. Bacterial food poisoning is usually caused by the consumption of food in which certain types of bacteria have been permitted to grow to large numbers. Moist, high protein foods which do not contain excessive concentrations of acid, salt or other inhibitors (e.g. many fishery products), provide ideal conditions for growth of food poisoning bacteria. Although some contamination with food poisoning bacteria is almost inevitable during handling and processing of fishery products, good hygienic practices and temperature control can keep the degree of contamination within acceptable limits and prevent outbreaks of illness.

Staphylococcus aureus is a food poisoning organism of particular interest in the present context, since it has been one of the main causes of rejection of crustacean shellfish products by the health authorities of importing countries. S. aureus is a part of the normal microbial flora of the skin, nose and throat of man and can be found in particularly large numbers in skin eruptions and inflammations (e.g. boils, acne) and wounds. The source of most staphylococci that enter fishery products during processing and preparation is the bodies of workers. The symptoms of staphylococcal food poisoning are caused by enterotoxins produced by the microorganisms during growth in food. The small numbers of staphylococci found in food as a result of initial contamination cannot cause illness. Contaminated food must be held under conditions which allow the staphylococci to grow to large numbers and produce harmful quantities of toxin.

S. aureus may be found on some raw seafoods at the time of catching or may enter raw products during primary handling and processing, e.g. filleting. However the staphylococci complete poorly with the normal spoilage flora of raw products and it is only if they are allowed to contaminate cooked products that they usually present a hazard. Because such a high proportion of humans carry staphylococci on their bodies, heat-processed seafoods are very likely to become contaminated during various handling operations and final preparation for consumption. Contamination of pre-cooked crustacean products (e.g. frozen prawns) is considered to present a particularly significant hazard because these products are commonly eaten without further cooking in salads, cocktails, etc., which may be exposed to elevated temperatures before and during serving. They also provide an excellent environment for staphylococcal growth.

Control of staphylococcal contamination of fishery products requires a high standard of personal hygiene among processing personnel, the use of procedures designed to minimise direct or indirect human contact with food, and stringent control of the temperature of the product at all stages of processing. S. aureus will not grow at temperatures below 6°C or above 46°C.

CONCLUSION

The preceding discussion has demonstrated that a variety of public health problems can be caused of fishery products produced under unsatisfactory conditions. The key element in control of all these illnesses is effective education and training. Managers and supervisors must be aware of the food-borne disease problems that confront the industry and must realise that the implementation of effective hygiene makes good economic sense. Examples of economic benefits derived from good sanitation and hygiene include: (1) prevention of the considerable losses incurred by processors who cause food-borne disease outbreaks, (2) production of a high quality product with good storage life and minimal spoilage losses, (3) elimination of rejections of unsatisfactory products by importing countries and customers, thereby expanding potential markets. Managers and supervisors must be capable of recognising unsatisfactory situations and must be able to take appropriate remedial action or obtain professional assistance.

Workers should be trained in safe procedures for handling and processing fishery products and in proper sanitation of equipment. They should understand that fishery products can be a source of hazardous micro-organisms and should know which steps in the operations they perform are critical in controlling pathogens. Managers and supervisors must motivate their employees to follow the procedures laid down. Fishermen should be able to identify potentially toxic fish in their areas and should be aware of the hazards associated with fish or shellfish taken from waters subject to pollution or growth of toxic micro-algae.

Regulatory personnel often have an important part to play in the education and training of those in the industry. They must be given sufficient knowledge to enable them to carry out this role effectively and to perform their regulatory functions intelligently.

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LECTURE 20

FOOD IRRADIATION - A VIABLE TECHNOLOGY FOR REDUCING POSTHARVEST LOSSES OF FOOD

P. LOAHARANU

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FOOD IRRADIATION - A VIABLE TECHNOLOGY FOR REDUCING POST HARVEST LOSSES OF FOOD

Paisan Loaharanu
Joint FAO/IAEA Division of Isotope and Radiation Applications
of Atomic Energy for Food and Agricultural Development
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna, Austria

ABSTRACT

Research and development in the past 30 years have clearly demonstrated that food irradiation is a safe, effective and environmentally clean process of food preservation. Twenty-seven countries have approved over 40 irradiated foods or groups of related food items for human consumption, either on an unconditional or a restricted basis. The technology is beginning to play an important role in reducing post-harvest losses of food and in facilitating wider distribution of food in the trade. Its wide application in solving microbial spoilage losses of food, insect disinfestation, improving hygienic qualities, slowing down physiological processes of foods is reviewed. Special emphasis is placed on applications of direct relevance to countries in Asia and the Pacific region.

INTRODUCTION

The increasing awareness of the need to reduce post-harvest losses of food may be illustrated by a resolution of the seventh special session of the United Nations General Assembly, adopted in September 1975, which stated that "the further reduction of post-harvest food losses in developing countries should be undertaken as a matter of priority with a view to reaching at least 50% reduction by 1985". Thus, every safe and effective method for combating food losses must be used to make more food available for mankind.

Food irradiation is gaining wider recognition and acceptance as a physical process of food preservation. In principle, this process involves exposing food either prepackaged or in bulk, in cans or in the dried or frozen state, to ionizing energy in the form of X-rays, gamma rays or electrons in a special room for a specified duration. At present, the most common source of ionizing energy for treating food and non-food products is ^{60}Co and, to a lesser extent, ^{137}Cs, which are so-called "radioisotope" sources. There are also "machine" sources, which can generate electrons or X-rays for food treatment. It is important to note that exposing foods or any material to ionizing energy from either ^{60}Co or ^{137}Cs or electrons (10 MeV maximum energy), or X-rays (5 MeV maximum energy), does not induce radioactivity in the materials treated, even at a radiation dose a thousand times greater than the highest dose contemplated for food preservation.

In general, the application of food irradiation may be summarized as follows:

<u>Low dose</u> (up to 1 kilogray)
- (a) inhibition of sprouting
- (b) insect disinfestation
- (c) delay of ripening

<u>Medium dose</u> (1 - 10 kilogray)
- (a) extension of food shelf-life
- (b) reduction of microbial load
- (c) improvements of technological properties of food

High dose (10 - 50 kilogray)

(a) commercial sterilization

(b) elimination of viruses.

SAFETY AND ACCEPTANCE OF IRRADIATED FOODS

The safety of food treated by ionizing energy was evaluated by several expert committees appointed by FAO, IAEA and WHO since 1964. The latest Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food (JECFI), convened in 1980, concluded that ionizing energy treatment of food commodities with an overall average dose of 10 kilogray or 1 Mrad caused no toxicological hazard for human consumption (1). This conclusion, as well as other recommendations of JECFI, were introduced into the system of the Codex Alimentarius Commission (CAC) with a view to establishing an international standard for irradiated foods. After elaboration under the Codex procedures, CAC decided to adopt a "Codex General Standard for Irradiated Foods" (treated up to an overall average dose of 10 kilogray), and a "Recommended International Code of Practice for the Operation of Radiation Facilities Used for the Treatment of Foods", at its 15th session held in July 1983 (2). The Codex Standard and Code of Practice have already been circulated to all member countries of the CAC for acceptance.

Following the above developments, national authorities have shown positive attitudes towards food irradiation processing. At present, 27 countries have approved collectively over 40 irradiated food items for human consumption, either on an unconditional or restricted basis. Countries such as Australia, Bangladesh, Canada, Chile, Denmark, England, France, Netherlands, USA and Yugoslavia have initiated steps to approve food irradiation as a process of food preservation, up to a certain maximum dose.

SPECIFIC APPLICATIONS OF FOOD IRRADIATION OF INTEREST TO COUNTRIES IN ASIA AND THE PACIFIC

1. A Substitute for Chemical Fumigation

Fumigation of food and food ingredients with various chemicals such as ethylene dibromide (EDB), methyl bromide (MB), ethylene oxide (ETO), etc., has been held suspect by health authorities, from both the health and occupational safety points of view. In the USA, the use of EDB as a food fumigant was banned by the Environmental Protection Agency as of 1 September 1984 except for treating fruits destined for export (3). Any food treated with EDB is also prohibited for sale in the USA, with the exception of mangoes, which is still permitted until 1 September 1985. The ban of EDB has deprived the fruit and vegetable industry in the USA of a strong and broad spectrum fumigant commonly used for overcoming quarantine restrictions against fruit fly infestation of these products.

Irradiation can be used instead of chemical fumigation in the following areas:

1.1 A quarantine treatment for fruits and vegetables

Without EDB, other fumigants such as MB and phosphine do not offer a broad spectrum for treating fruits and vegetables. Physical processes such as cold storage and heat treatment which are capable of insect disinfestation of fruits and vegetables also have limitations. Irradiation appears to offer the most viable alternative for this purpose. The irradiation dose required for fruit fly disinfestation to satisfy quarantine regulations (0.25 kilogray) does not change physico-chemical and organoleptic properties of most fruits and vegetables. A dose as low as 0.1 kilogray would prevent eggs of most fruit fly species from developing into adults (4).

1.2 A physical method for insect disinfestation of stored products

The safety of methyl bromide, the most widely used fumigant for insect disinfestation of food grain and other stored products, appears to be in doubt. At best, methyl bromide fumigation could provide a short term solution to overcome infestation problems. In addition, insects are capable of developing resistance to most chemicals. Irradiation offers a good potential to replace MB fumigation whenever the use of this chemical is prohibited. A radiation dose of between 0.25 and 0.50 kilogray is sufficient for disinfestation of most, if not all, species of stored-product insects. Already, two large electron accelerators have been in operation for insect disinfestation of imported food grain at Port Odessa, USSR, since 1980. Each machine (1.4 MeV, 20 kW) is capable of treating an average of 200 tons of grain per hour at a dose of between 0.20 and 0.40 kilogray (5). Calculation of the techno-economic characteristics of radiation aided disinfestation and fumigation with methyl bromide shows the former method to be more economical, especially when disinfesting grain unloaded from ships, given an annual volume of 400,000-500,000 tons.

1.3 A method for decontamination of spices and other food ingredients

Spices and other food ingredients destined for incorporation into processed foods such as canned meat, sausages, soup, etc., have to comply with certain microbiological specifications. Up to now, ethylene oxide (ETO) has been generally used for microbial decontamination of these products. The use of ETO appears to be limited in the near future in view of the increasing regulatory restrictions in Europe, Japan and the USA. Irradiation with a dose up to 10 kilogray provides the most viable alternative to ETO fumigation of spices and other food ingredients. The use of irradiation to decontaminate spices and other food ingredients is being carried out on a commercial scale in Belgium, France, Hungary, the Netherlands and the USA.

2. Disinfestation and Decontamination of Fishery Products

Countries in Asia and the Pacific are the major producers and exporters of fishery products. Irradiation offers potentials in the following applications for these products:

2.1 Insect disinfestation of dried and cured fish

Dried and cured fish are normally infested by insects of several species, both during sun-drying and storage. In some countries, the use of insecticides to disinfest insects in these products is still being practiced. Such use is meant to reduce high losses caused by insect infestation without giving much consideration to health implications for the consumer. Irradiation with a dose up to 0.5 kilogray is effective for insect disinfestation of dried and cured fish (6). If properly packaged, irradiated dried and cured fish can be kept insect-free at room temperature for several months.

2.2 Elimination of certain pathogens in frozen seafood

Fish and shellfish caught in polluted water and/or subjected to human handling during processing are occasionally contaminated by *Salmonella*. In the case of frog legs, *Salmonella* contamination is quite common as live frogs normally live in polluted environments. Chlorination and freezing of these products cannot eliminated *Salmonella* completely from these processed products. Irradiation offers an ideal solution for the elimination of this pathogen and the product can be treated even in a frozen condition. A dose of between 3 and 5 kilogray would eliminate a minimum of 6 log cycles of all serotypes of *Salmonella* in frozen seafood and frog legs without causing an adverse effect on the quality (7). Commercial scale irradiation of frozen seafood and frog legs is being carried out in Belgium and the Netherlands.

3. Sprout Inhibition of Root Crops

Certain root crops such as potatoes, onions and garlic undergo physiological deterioration in addition to being attacked by microorganisms during storage. Among the losses due to physiological factors, sprouting is the most important cause of deterioration (8, 9). In countries where ambient temperatures are high, sprouting of root crops occurs much earlier than in temperate or cold countries. In addition, chemical sprout inhibitors are not effective under tropical conditions.

Irradiation with a dose of 0.1 kilogray is effective for sprout inhibition of all root crops provided that the treatment is carried out when they are in the dormant state (within one month after harvesting). Certain root crops such as potatoes should be cured, irradiated and stored in the same container to minimize handling damages during and following irradiation. Irradiated potatoes should be stored at approximately 10°C to reduce losses caused by spoilage microorganisms.

COMMERCIALIZATION OF IRRADIATED FOODS

The number of countries which commercialize irradiated food is growing. Following the first successful commercial facility for irradiating potatoes built by Shihoro Agricultural Cooperative in Hokkaido, Japan in 1973, other countries such as Belgium, the Netherlands, South Africa and the USA have used their commercial irradiators designed mainly for sterilizing disposable medical products for treating food and food ingredients as well. Irradiators which are available for treating food or feed on a commercial scale in different countries are listed in Table 1. Recently, countries such as France, Hungary, Italy, South Africa and the USA have constructed or are constructing irradiation facilities solely for treating foods. The irradiators which are being constructed or are planned for treating food/feed on a commercial scale are listed in Table 2. Developing countries such as Bangladesh, the People's Republic of China, the Republic of Korea, Mexico, Pakistan and Thailand are either considering or are planning the commercialization of food irradiation processing in the near future.

CONCLUSIONS

After more than three decades of research and development, food irradiation has been shown to be a safe and viable technology for reducing post-harvest losses of food. Its broad spectrum could solve the problems of spoilage losses of food items of economic significance to developing countries as well as overcoming certain barriers in international trade of food. At a time when a portion of the population is still facing hunger and mulnutrition, food irradiation provides another viable tool to combat the high rate of food losses in developing countries and to make more food available to mankind.

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TABLE 1: COMMERCIAL IRRADIATORS AVAILABLE FOR TREATING FOOD/FEED

Country	Commercial Irradiator Location	Status	Products Treated	Approx. Capacity
BELGIUM	MEDIRIS* Fleurus	completed (1980)	spices, animal feed, frozen seafood	3,000 tons/year
BRAZIL	EMBRARAD* Sao Paulo	completed	spices	---
CHINA, PEOPLE'S REP.	Multipurpose irradiator (180 kCi) Chengdu	completed	---	---
	Multipurpose irradiator (100 kCi) Shanghai	completed	---	---
ISRAEL	Animal Feed Irradiator (accelerator) Tel Aviv	completed (1984)	animal feed	---
JAPAN	Shihoro Potato Irradiator Shihoro, Hokkaido	completed (1973)	potatoes	15,000 tons/month
NETHERLANDS	Pilot Plant for Food Irradiation Wageningen	completed (1968)	shrimp, frog legs, organic dyes, spices	1,500 tons/year
	GAMMASTER-1* Ede	completed (1972)	spices, frozen frog legs, shrimp	5,000 tons/year
	GAMMASTER-2 Multipurpose Ede	completed (1982)	spices, frozen frog legs, shrimp	5,000 tons/year
SOUTH AFRICA	Fruit & Vegetable Irradiator Tzaneen	completed (1982)	mangoes, strawberries, potatoes, onions, etc.	7,000 tons/year
	Iso-Ster (Pty.), Ltd.* Kempton Park	completed (1981)	fruits, vegetables, coconut powder	---
	Multipurpose Irradiator Atomic Energy Board, Pretoria	completed	fruits, vegetables, chicken, etc.	---

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TABLE 1 (continued)

Country	Commercial Irradiator Location	Status	Products Treated	Approx. Capacity
TAIWAN	Multipurpose Irradiator	completed	---	---
USA	Radiation Technology, Inc. Rockaway, New Jersey	completed (few irradiators)	spices, seasonings	500 tons/year
	Isomedix, Inc. Whipany, New York	completed (several irradiators)	spices, seasonings	500 tons/year
	International Nutronics Irvine, California	completed (several irradiators)	spices, seasonings	500 tons/year
USSR	Grain irradiators (two electron accelerators) Port Odessa	completed (1981)	grain	400,000 tons/year

* Mainly used for sterilizing medical supplies

TABLE 2: COMMERCIAL IRRADIATORS PLANNED FOR TREATING FOOD/FEED (January 1985)

Country	Commercial Irradiator Location	Status	Products Treated	Approx. Capacity
BANGLADESH	Multipurpose irradiator (150 kCi) Dhaka	planned for 1985	potatoes, onions, fish	---
CHINA, PEOPLE'S REP.	Multipurpose irradiator (200 kCI) Shanghai	under construction	food in general	---
ECUADOR	Electron accelerator Quito	under construction	dried food	---
FRANCE	Pallet irradiator (2 million kCi ^{60}Co) Marseilles	planned for 1985	food in general	---
	CGR 10 MeV accelerator	planned for 1986	deboned poultry	---
HUNGARY	AGROSTER Joint Co. Budapest	planned for 1985	spices, potatoes, onions	---
IRAN	Multipurpose irradiator Tehran	planned for 1986	dried food	---
ITALY	Commercial Vegetable Irradiator Fucino Cooperative, Fucino	under construction	potatoes, onions, garlic	25,000 tons/season
PAKISTAN	Multipurpose irradiator Karachi	planned for 1986	food in general	---
THAILAND	Multipurpose irradiator (200 kCi) Bangkok	planned for 1986	food in general	---
USA	International Nutronics Honolulu, Hawaii	planned for 1985	tropical fruit	---

LECTURE 21

FOOD PROCESSING USING ELECTRONS & X-RAYS

J. CLOUSTON

FOOD PROCESSING USING ELECTRONS AND X-RAYS

The ionizing radiation which will be used as process energy for the preservation of food, will be limited to high energy electrons (less than 10 MeV), X-rays (less than 5 MeV) and gamma rays emitted by cobalt-60 (1.17;1.33 MeV) and cesium -137 (0.663 MeV). When a foodstuff is irradiated with any of these radiations absorption of the radiant energy will initiate a variety of reactions between its atomic and molecular constituents causing permanent chemical, physical and biological changes. Although this paper focusses on radiation processing using electron or X-ray generators in the range 2 to 10 MeV it is fundamentally important, for any application, to realise that, for all practical purposes, the various interactions of electrons, X-rays and gamma rays with food and its packaging are specific to the electrons in the substances and not the nuclei. To a very good approximation the penetrability of any material depends only on the numbers and kinds of atoms present irrespective of the manner in which they are chemically combined. In other words the range of a high energy electron in different materials is simply related to the number of electrons per unit volume.

When a high energy electron travels into a foodstuff it loses its energy by collisions with the bound electrons of the substance and by emitting electromagnetic radiation called "bremmstrahlung". This radiation may have any energy from zero up to the energy of the electron less 0.51 MeV, and is fairly uniformly distributed over the whole range. Thus, a 10 MeV electron may emit bremmstrahlung having an energy of 9.49 MeV which, in terms of its physical interactions with the substance and therefore its penetrability, is indistinguishable from gamma radiation.

Unlike electron radiation, the penetration of gamma and X-radiation cannot be described by a range-energy relationship. Gamma energy can be lost by several processes each of which produces ions and energetic free electrons, which activate molecular and atomic species, and which cause the same permanent physical, chemical and biological change that results from electron irradiation. The penetrability of an X- or gamma ray depends on the probability that the photon can travel a given distance without an energy loss collision which causes it to lose some or all of its energy. The probability for a single total energy loss collision decays exponentially, while the probability of fractional loss of energy by several collisions initially decays somewhat less than exponentially but gradually approaches exponential decay. This secondary effect is called the "build-up" factor and is important in shielding design but will also contribute to the dose when dense materials are irradiated by X- or gamma rays.

The processes mentioned, refer to the fundamental mechanisms whereby the incident radiant energy is absorbed in a foodstuff. As the electron or gamma ray energy increases radioactive atoms may be activated by the ejection of particle from nuclei by high energy photons or by excitation of nuclei by high energy electrons. Table 1 lists the threshold energy levels for induced radioactivity by irradiation with X- or gamma photons.

For low energy gamma radiation such as that from cobalt-60 or cesium-137 the problem does not exist. However, the bremmstrahlung component associated with high energy electron irradiation means that in principal at least a radioactive beryllium atom could be activated by the absorption of a 1.7 MeV bremmstrahlung photon when a foodstuff is irradiated with a 2.21 MeV electron beam. Table 1 lists the threshold energy levels very approximately in order of their abundance in foods.

These physical interactions which have been carefully considered by International expert committees have contributed to the WHO recommendation that electrons up to 10 MeV may safely be used for the irradiation of food but the energy of X-rays (bremmstrahlung) may not exceed 5 MeV when used as an alternative to gamma radiation. These recommendations mean that electron accelerating machines which can be switched from the electron mode to the X-ray mode may be used instead of cobalt-60 or cesium-137 for some applications.

Whether machines will replace radioactive sources depends on the cost, convenience and reliability. This paper discusses accelerating machines which can operate above 2 MeV and the cost.

RADIATION PROCESSING

An absorbed kilowatt of ionizing radiation, whether it be produced by a radioactive source or an electron accelerator operating in the electron or the X-ray mode will process 3600 kg of product to dose of one kilogray per hour namely;

$$kg/h = (2.8 \times 10^{-4} \times \eta \times kW / kGy$$

Consequently, powerful kilowatt sources of high energy radiation are required to process commercial quantities of foods. The processing rate will be related to the efficiency (η) with which the energy emitted by the source is absorbed by the product and, of course, the processing rate in kilogram per kilowatt will decrease as the specified dose in kilogray increases.

Referring to Figure 1 which depicts the dose-depth relation in water for 2 and 20 MeV electrons together with cobalt-60 and cesium-137 gamma radiation the advantages for gamma radiation when related to the thickness and density of many packaged foods are obvious. This advantage is highlighted by the fact that the design of industrial gamma irradiators ensures that first one side of a package and then the other is irradiated thereby increasing the effective thickness by about 80%.

A picture of the broad electron beam dose distribution with depth for low atomic number (Z) materials is provided in Figure 2 by the curve labelled dF/dR vs R. The abscissa R is the thickness per unit energy (electrons/cm^2- MeV). The relative dose (ionization density) in each layer of low-Z material is dF/dR. The area under this curve has been normalised to unity. Thus F will represent the fractions of the incident beam energy which is absorbed in a food of thickness

R or

$$F = \int_0^R (dF/dR) \; dR$$

and F/R is the average fractional dose per sample. Cheek and Linnenbom (1) chose the dimensions of R as follows; the stopping power of an element is proportional to the electron density NZ/A where N is Avogadros number, Z is the atomic number and A is the atomic weight. The ratio Z/A is approximately 0.5 for all light elements except hydrogen for which it is 1.0. Consequently, the distribution of energy loss as a function of thickness in g/cm^2 is almost the same for all light materials not containing hydrogen. Substances such as food containing appreciable amounts of hydrogen may have significantly different electron densities per gram. The distribution curve for electrons in water and aluminium differ appreciably when the thickness is expressed in g/cm^2 but not if the thickness is expressed in electrons/cm^2. Because the relative distribution of ionization in depth in a substance is closely proportional to the electron energy, a specific thickness R can be obtained and expressed as electrons/cm^2- MeV. Dose depth data for electron energies from 0.5 MeV to 5.0 MeV may thus be represented by a single curve shown as dF/dR vs R. Consequently, the specific thickness of any food can be calculated from the relationship

$$R = (\rho \times L \times N \times \sum_i f^i \times (Z/A)^i) \; /E$$

where ρ is the density (g/cm^3),L thickness (cm), E electron energy (MeV), f^i the fraction by weight of the i'th element present in the food and $N \times f^i \times (Z/A)^i$ is the number of electrons /g. Assuming a uniform lateral dose distribution and negligible back scatter a sheet of food of thickness d passing an electron beam scanned over a width s with a velocity v cm/s will receive an average absorbed dose

$$D = (n \times E \times I \times 10^3) \; / \; (d \times v \times s \times \rho) \text{ Gray}$$

It is important to note that:

(i) the depth dose at which the absorbed dose is a maximum corresponds to $R = 0.49 \times 10^{23}$ namely the maximum of the dF/dR vs R curve.

(ii) The package thickness at which maximum average absorbed dose is obtained is $R = 0.74 \times 10^{23}$ from the curve F/R vs R.

(iii) The sample thickness when the exit dose equals the entrance dose is $R = 0.98 \times 10^{23}$ (from the curve dF/dR vs R) and at this thickness 87% of the beam energy has been absorbed.

(iv) If the processing system can irradiate first one side and then the other the effective thickness is increased about 2.4 times for the same incident electron energy. The depth dose relationship for electrons in the range 0.5 to 16 MeV for a single sided irradiation of water is shown in Figure 3 a, b.

RADIATION SOURCES

One megacurie of cobalt-60, producing approximately 15kW of gamma power will process about 17 tonnes/h (408 te/d) when the specified dose is 1 kilogray and the photon efficiency is 30% whereas 4.57 megacuries of cesium-137 would be needed to treat the same quantity. Industrial radioactive sources are manufactured by governmental nuclear power and research centres in Europe and North America. More than 95% of the industrial cobalt-60 is produced by Atomic Energy of Canada Ltd, and the remainder is produced by France, USSR and the USA which also fabricate cesium-137 sources for industrial use. The current world supply of cobalt-60 is about 75 megacurie which is mostly dedicated to the supply and replenishment of sources for medical therapy and medical product sterilisation. It has been estimated that, if the entire world supply of cobalt-60 was re-orientated to food processing it would be sufficient to treat 30,000 te/d to one kilogray. The present world supply of cesium-137 would process about 7,900 te for a maximum throughput of 1,500,000 te/y which is a trivial portion of the world food supply that could benefit from being processed by ionizing radiation. Consequently, should a significant demand for ionizing energy as food processing energy develop it will be met by electrically driven accelerator sources particularly if the demand for cobalt-60 increases to the extent where dedicated reactors will need to be built.

Although low density bulk foods such as grain and flour are suitable for processing with electrons up to 3 MeV and machines able to produce electrons in the 5 - 10 MeV are being manufactured for industrial use the conversion of electrons to X-rays (bremmstrahlung) will be necessary for many applications. Whether this technology will be a practical radiation source for industrial processing will depend on the cost per unit of product treated to a specified dose.

ELECTRON BEAM AND BREMMSTRAHLUNG SOURCES

Several industrial radiation applications are based on the use of various designs of electron accelerators within the 10 MeV limit proposed for food processing. The design principal and characteristics are summarised in Table 2.

New high power electron accelerators with potential for large scale commercial applications are presently being designed, constructed and tested. Bremmstrahlung is produced by causing the electron beam to collide with a heavy metal converter plate. Figure 4. The electron energy is degraded to electromagnetic energy and heat when the beam is completely stopped. The X-rays emerge from the rear of the converter plate and the heat is removed by copious water cooling. If the machine is designed for dual mode operation the 5 MeV electrons will produce 5 MeV X-rays which for the most part will be emitted in a direction closely aligned with the original direction of the electron beam. The overall efficiency is poor. If for example, a Pb stopping plate is used with 5 MeV electrons then 92% of the energy is converted to heat. Consequently a 5 MeV X-ray generator with an output equivalent to 1MCi of cobalt-60 must produce 112kW of electron beam power to provide a radiative X-ray power of 9kW for processing 17te/h to 1kGy. Such questions as cost and reliability have been reasonably answered for electron machines up to 3 MeV. Machines producing 4.5 MeV electrons are being industrially operated for commercial scale processing of plastics and rubber. Several 4.5 MeV machines known as DynaX have been constructed and installed during 1983-1984. These machines will provide data and experience on the reliability and cost effectiveness for dual mode operation.

Product handling using gamma radiation sources uses conveyors which allow multiple passes of packages about the source and adequate depth to achieve a photon efficiency of 25-30%. An X-ray source, such as that produced by a 4.5 MeV Dyna-X contains a broad band of photon energy as shown in Figure 4 for 5 MeV bremmstrahlung.By judicious filtering using a Pb filter the average X-ray energy increases from 1.06 to 1.6 MeV but reduces the overall conversion to about 4% thereby demanding about 220kW of electron beam power to equate with a megacurie of cobalt-60. These factors mean that the present proven machine design for a 150 kW, 4.5 MeV Dyna-X design would equate with about 500,000 Ci of cobalt-60 when operating in the X-mode. It would therefore need to be processing products suitable for electron beam irradiation for part of the time to be profitable.

A comparison of the dose uniformity for a 60 cm thick package filled with a 0.75 g/cm^3 food when irradiated with cobalt-60 gamma rays, cesium-137 gamma rays and 5 MeV bremmstrahlung is presented in Figure 5. In principle, the X-rays produce a superior dose distribution for two-side irradiation.

At energies of 5 MeV and above a Linear Accelerator is the preferred device because the absence of static high voltage eliminates problems due to the breakdown of insulation and therefore long periods of trouble free operation can be expected. The Linac differs from the conventional electrostatic accelerating tube because it makes use of the fact that when a radiowave travels along a tube of width comparable with its wavelength and electric vector acting along the axis of the tube is produced. Electrons injected into the evacuated tube are eventually carried along by the speed of the wave and by suitable design this speed can be any fraction of the speed of light. Energies in the range 5 MeV to 10 MeV are readily obtainable and machines designed for 40kW of beam power are being manufactured.

MACHINE TECHNOLOGY FOR FOOD PROCESSING

Although the different machines and radioactive sources that are commercially available can be integrated with a food processing industry the limitation to 10 MeV for electrons and 5 MeV for X-rays restricts the use of 10 MeV electrons to foods and low atomic number packaging materials with a package thickness of 15cm or less when the density is 0.5g/cm^3 and proportionally thinner of thicker packages for lower and higher densities. As illustrated by Figure 5 a 5 MeV machine operating in the X-ray mode would adequately cope with large dense packages and depending on the machine power would compete with a gamma radiation source of equivalent radiative power.

DUAL MODE ELECTRON X-RAY PROCESSING

The capital cost for a machine, shielding and warehouse would approach US$ 5,000,000 and for this reason a food irradiation facility must be able to handle large volumes of food safely and economically. A 4.0 MeV, 100 kW Dynamitron machine with its shielding and support systems would cost about US$ 3,000,000 in 1984 dollars. Assuming a 30% gross return on capital the revenue from processing would need to be $1,500,000 or $250 per hour for a 6000 h/y operation. When processing in the electron mode with 50% efficiency the machine would treat 180,000 kg/h to 1 kGy and operating in the X mode about 12,000 kg/h.

From an operational point of view the most efficient facility is one dedicated to the treatment of a single product to a specified dose of radiation. A detailed economic evaluation for a hypothetical situation serves little purpose however, simple arithmetic suggests that an X-ray dose of 3 kGy could be delivered to about 2000 x 2kg chickens per hour to reduce the salmonella count by 6-8 log cycles for about 12.5c each. A 10 MeV, 25 kW electron linear accelerator with about the same initial all up cost would electron process the same quantity for about 5c each. However, a 10 MeV machine operating in the X-ray mode could not be used for food and the penetrability of a 5.0 MeV Linac would not be sufficient to ensure adequate treatment of whole chickens.

For low dose treatments of low density products, machines in the 2-5 MeV range are being operated commercially for special industrial processes. The medical supply industry is experimenting with dual mode 4.5 MeV machines and a 10 MeV linear accelerator has been built in France for the irradiation of boneless chicken meat to make it salmonella free. These machines will test the technology for food irradiation and the success or failure of these original ventures will determine the extent of machine use world-wide. Because of the quantities of food involved X-ray and electron beam machines will be necessary to establish and expand large scale food irradiation processing.

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Element	Type of nuclear change	Threshold energy (MeV)	Half-life of product
^{12}C	(γ, n)	18·7	21 min
^{16}O	(γ, n)	16·3	2·1 min
^{14}N	(γ, n)	10·65	10 min
^{31}P	(γ, n)	12·35	25 min
^{39}K	(γ, n)	13·2	7·5 sec
^{32}S	(γ, n)	14·8	3·2 sec
^{40}Ca	(γ, n)	15·9	1 sec
^{54}Fe	(γ, n)	13·8	8·9 min
^{24}Mg	(γ, n)	16·2	11·6 sec
^{25}Mg	(γ, p)	11·5	14·8 h
^{26}Mg	(γ, p)	14·0	62 sec
^{63}Cu	(γ, n)	10·9	10 min
^{65}Cu	(γ, n)	10·2	12·8 h
^{127}I	(γ, n)	9·3	13 days
^{81}Br	(γ, n)	10·7	6·4 min
^{27}Al	(γ, n)	14·0	7 sec
^{28}Si	(γ, n)	16·8	5 sec
^{7}Li	(γ, p)	9·8	0·85 sec
^{9}Be	(γ, n)	1·67	very short
^{2}H	(γ, n)	2·2	
^{22}Na	(γ, n)	2.6	2.6y

THRESHOLD ENERGY LEVELS FOR THE PRODUCTION OF INDUCED RADIOACTIVITY IN VARIOUS ELEMENTS BY IRRADIATION WITH HIGH ENERGY ELECTROMAGNETIC RADIATION. THE ELEMENTS ARE LISTED VERY APPROXIMATELY IN ORDER OF THEIR ABUNDANCE IN BIOLOGICAL MATERIAL.

TABLE 1.

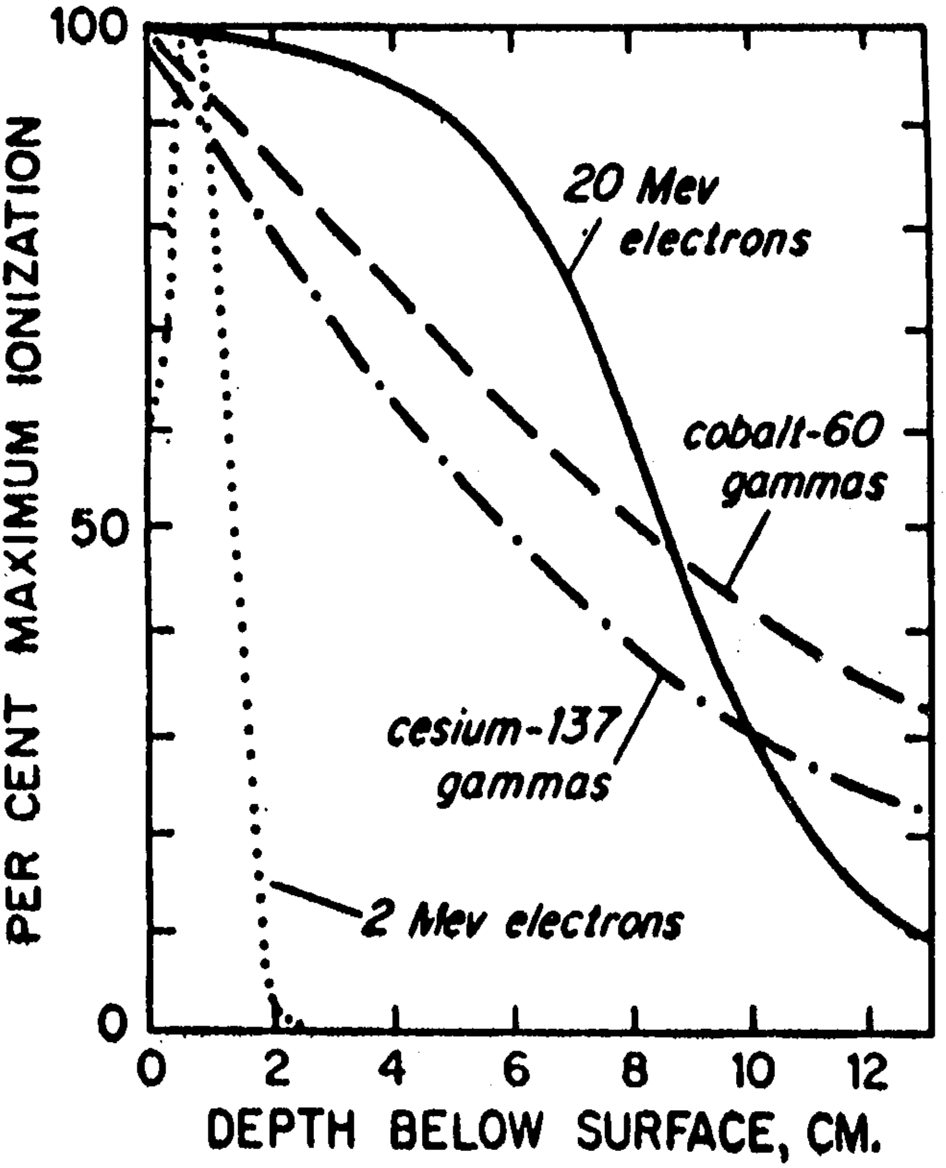
TABLE 2.

Types and Typical Performance Parameters for Commercially Available Electron Accelerators.

Accelerator	Beam Energy (MeV)	Average Beam (kW)	Beam Type	Basis of Operation
Linear	1 to 32	0.3 to 40	Pulsed; Continuous Wave (CW)	High voltage, radio frequency (rf) wave
Dynamitron	4.5 (max.)	up to 150	Direct Current (DC)	Cockcroft-Walton technology
Resonant Transformer	4.0 (max.)	up to 40	DC	High-voltage, insulated core transformer
Van der Graff Electrostatic Generator	3 (air) 10 (pressure tank)	low	DC	Moving belt, discharge

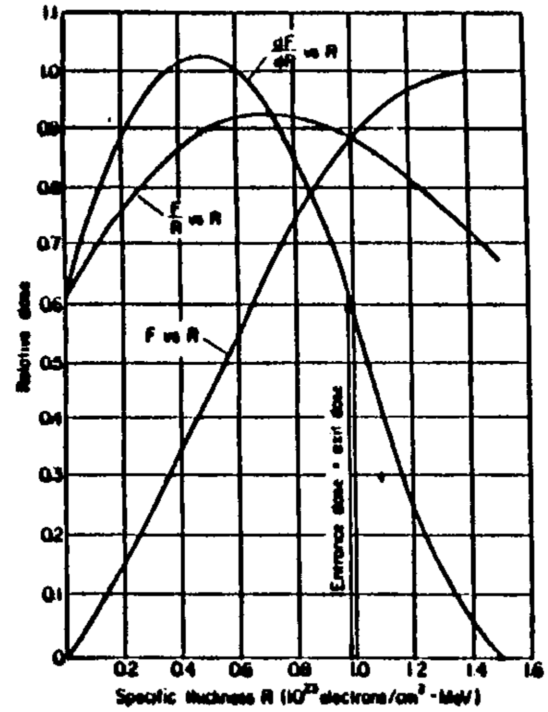
New Electron Accelerators with Potential for Large-Scale Applications				
High Power RF Linac	10 MeV	500 kW	Pulsed CW	Conceptual Design
Induction	10 MeV	Megawatts	Pulsed CW	Modular components Tested at LLNL*

(*) Lawrence Livermore National Laboratory



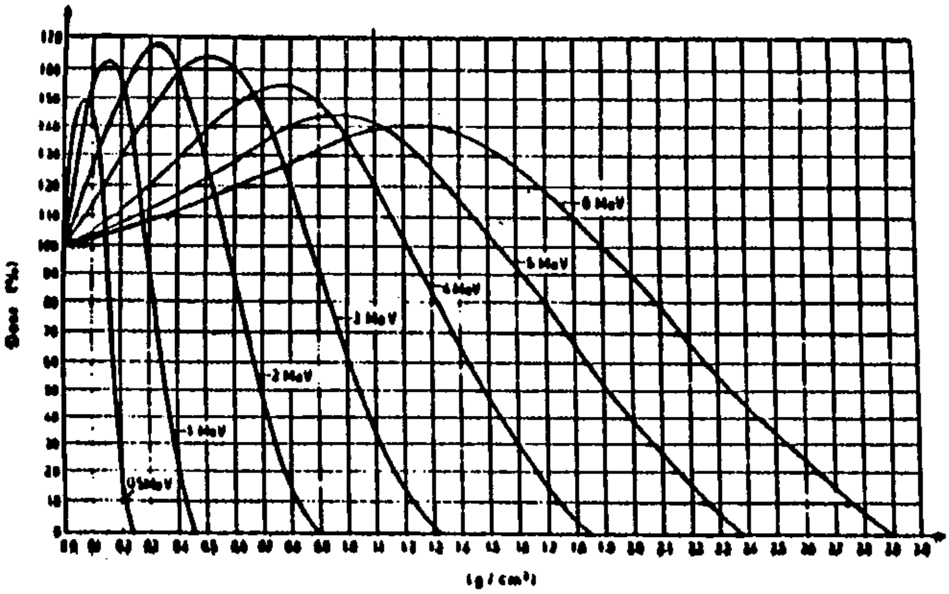
DOSE-DEPTH RELATION FOR ELECTRONS AND GAMMA RAY SOURCES

FIGURE 1.



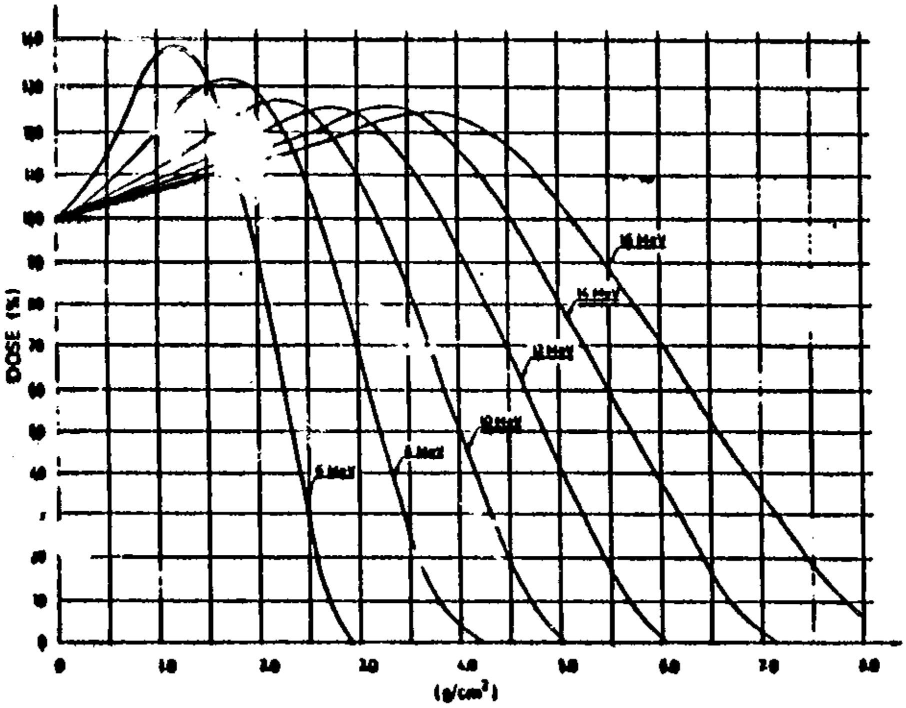
DOSE DISTRIBUTION WITH DEPTH IN LOW-Z MATERIALS. F IS THE FRACTION OF THE TOTAL BEAM ENERGY ABSORBED (CHEEK AND LINNENBOM, 1960).

FIGURE 2.



Penetrability of electron with energies 0.5 MeV to 6 MeV

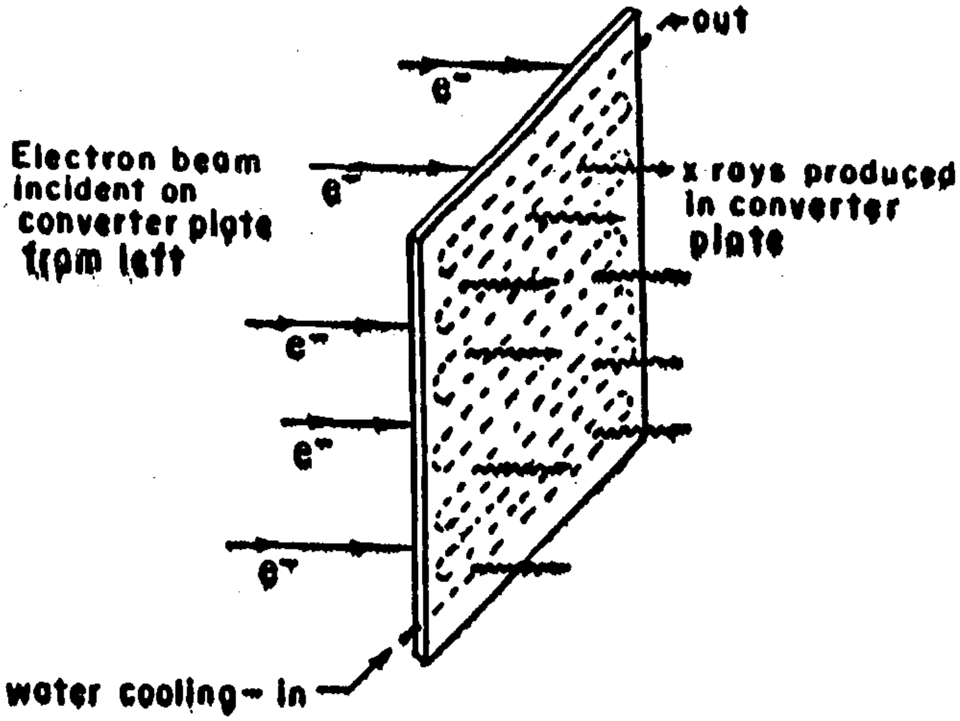
Figure 3a



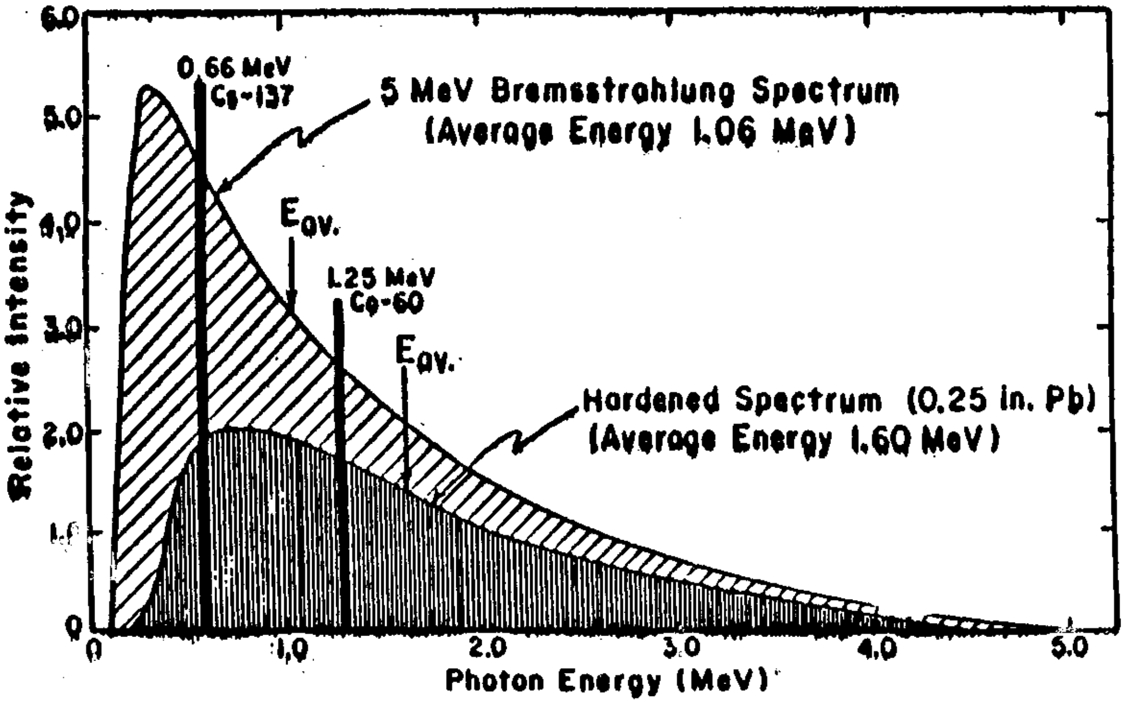
Penetrability of electron with energies 6.0 MeV to 16 MeV

Figure 3b

Bremsstrahlung Radiation

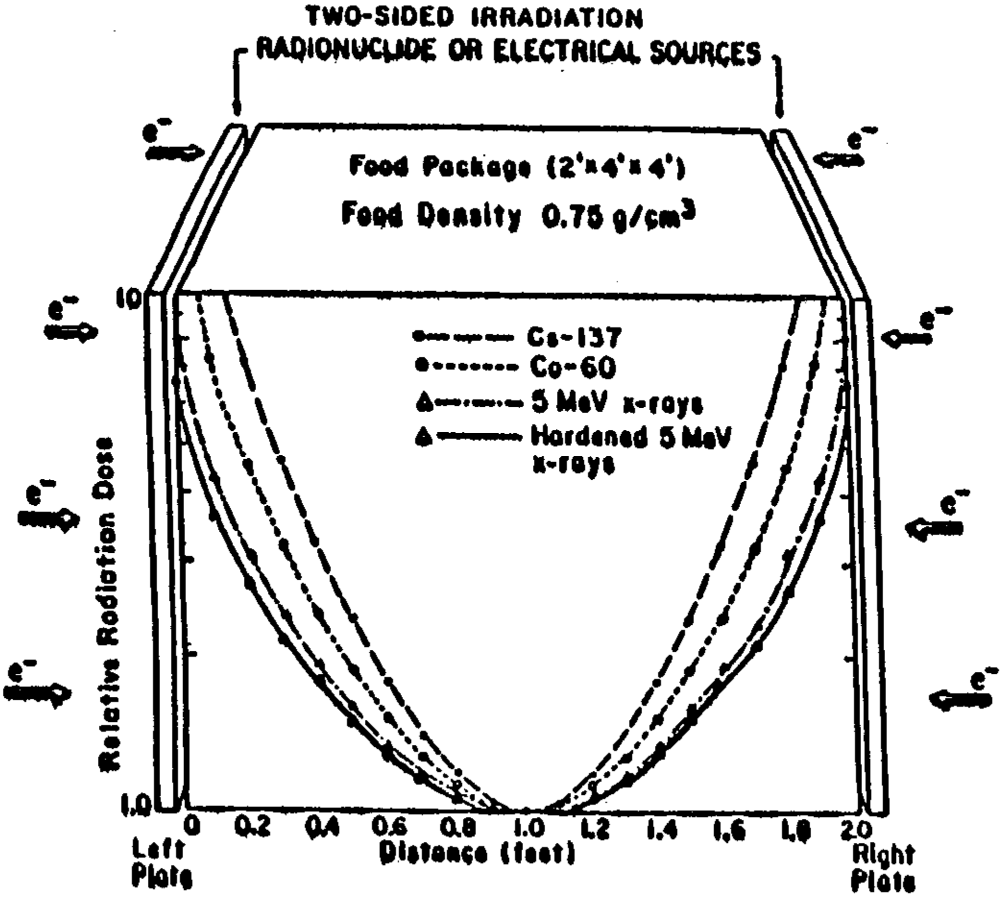


ELECTRON-TO-X RAYS (BREMMSTRAHLUNG) CONVERSION



COMPARISON OF PHOTON ENERGY SPECTRA FOR CO-60 AND CS-137 RADIONUCLIDE SOURCES WITH X RAYS (BREMMSTRAHLUNG) SPECTRA (FILTERED AND UNFILTERED) FROM A 5-MEV ELECTRON ACCELERATOR.

FIGURE 4.



COMPARISON OF DOSE-DEPTH RATIOS FOR Co-60 AND Cs-137 RADIONUCLIDE SOURCES WITH FILTERED (HARDENED) AND UNFILTERED X RADIATION FROM A 5-MEV ELECTRON ACCELERATOR, ON A 2X4X4 FT FOOD PACKAGE (0.75 G/CM^3).

FIGURE 5.

LECTURE 22

FOOD IRRADIATION BY LOW ENERGY ELECTRONS

J. BIRD

FOOD IRRADIATION BY LOW ENERGY ELECTRONS

J R BIRD
(1985)

CHOICE OF METHOD

For some special cases, the use of low energy electrons has advantages over the use of gamma-rays or higher energy electrons for the direct irradiation of food. These advantages arise from details of the interaction processes which are responsible for the production of physical, chemical and biological effects (1). Factors involved include:

Depth of penetration;
Dose distribution;
Irradiation geometry; the possible production of
Radioactivity; and
Costs.

Depth of Penetration

Electrons interact directly with atomic electrons in a sample causing excitation, ionisation and the breaking of chemical bonds. As a consequence, the electrons lose energy and irradiation is restricted to a region which is a few mm to a few cm thick - depending on the electron energy. By contrast, gamma-rays can travel many centimetres or even metres before any interaction occurs - the distance depends on the density and atomic number of the atoms in the sample. As an example, 1.3 MeV electrons are useful for the irradiation of organic materials less than 5mm thick whereas Cobalt gamma-rays of similar energy can be used to irradiate material at least two orders of magnitude thicker.

Dose Distribution

Electron interactions lead to x-ray emission and, at

MeV energies, to the direct emission of photons (bremmstrahlung). Energy is also transferred to scattered electrons and an electron/photon cascade builds up within a sample. This cascade controls the energy density or dose distribution as a function of depth of penetration within a sample. Some examples, calculated from cascade models are given in Figure 1. Photon production increases with electron energy and the atomic number of sample atoms. Dose distributions are therefore broadened as the incident electron energy is increased.

The ratio of the dose at the surface to the peak dose at some depth within the sample decreases as electron energy increases. This is important in food irradiation since some specified minimum dose must be given to all parts of the sample in order to achieve the required effect. Having selected this minimum dose, which defines the necessary surface dose, the curves in Figure 1 can be used to determine the maximum usable depth. This is the depth at which the dose again falls to the minimum allowable value (A points in Figure 1).

The usable depth (t cm) is found to be approximately linear with electron energy (E MeV). For example:-

Polyethylene (H/C = 2) $t = 0.38E - 0.12$ (1)
Polystyrene (H/C = 1) $t = 0.40E - 0.13$ (2)
Carbon $t = 0.44E - 0.14$ (3)

The dose variation ((DMAX-DMIN)/DMIN) can also be obtained from Figure 1 and this is shown in Figure 2 for H/C = 1. It increases rapidly from 0.5 to 1.0 MeV and then rises relatively slowly.

The fraction of the beam energy which is dissipated beyond the A points is wasted (shaded area at the right of Figure 3). This decreases as the incident energy is increased. In practice, the electron beam is accelerated under vacuum and then allowed to pass through a thin metal window (e.g. 50 μmTi) and an air gap (e.g. 10 cm) before reaching the sample. This has several effects:

(a) The energy dissipated in the window and air gap is wasted (shaded area at the left of Figure 3);
(b) The electron/photon cascade begins in the window and the dose at the sample surface is increased;
(c) The electron energy at the sample surface is reduced typically by 50 to 100 keV.

The useful fraction of the beam energy can be taken as the area between the surface dose and exit dose for the curves in Figure 1 and these are shown as curve 1 in Figure 4. Curve 2 is obtained by assuming that the surface dose is all that is needed to achieve the desired effect and the energy expended in achieving higher doses at the centre of the irradiated region is also wasted (shaded area at the top of Figure 3). The useful fractions increase only slowly above 1 MeV.

An important difference between electron and gamma-ray irradiation is that an electron beam is uni-directional and its energy is immediately effective as it penetrates sample material. Gamma-rays from a point source have an intensity which follows a $1/d^2$ law (d is the distance for the source) as well as an exponential attenuation in sample material. The available energy is thus distributed very non-uniformly over a large volume and movement of material is necessary to achieve sufficient uniformity of dose.

An intermediate situation applies to the use of an electron beam to generate x-rays which then irradiate the sample material. X-ray production is concentrated in a forward cone which narrows as the electron energy is increased. The effects of solid angle and attenuation still apply, but it is easier to achieve reasonably uniform doses. The main drawback with this method is the poor efficiency for conversion of electron power to x-ray power. This efficiency is less than 10% for electrons with energies below 3 MeV incident on a high Z target. Since high efficiency can be achieved in the production of an electron beam and in its use for direct irradiation of a sample it is worthwhile to consider ways to increase the volumes which can be irradiated.

Two-sided Irradiation

If a thin sheet of material is irradiated from both sides, the dose distribution will be as shown in Figure 5 for the case in which the thickness is such that the dose at the centre is equal to the surface dose. This thickness is twice the thickness at which the distributions in Figure 1 fall to 50% of the surface dose (B points). A comparison of the usable thickness for one-sided and two-sided irradiations is shown in Figure 6. Twice the electron beam power must be used in two-sided irradiation but the usable thickness is increased by a factor of approximately 2.5 indicating that a greater proportion of the beam power is usefully applied. The only losses are from the small fraction of electrons or photons which are scattered out of the sample. The usable fraction is shown as curve 3 in Figure 4.

Rotating Sample

If a cylindrical sample is rotated within an electron beam, which has a range comparable to the cylinder radius, a similar dose distribution will be obtained to that for a thin sheet. An approximate estimate is included as the dashed curve in Figure 5. The surface dose is relatively higher than that for a thin sheet and the use of a smaller cylinder would result in considerably less dose variation with depth. However, a slightly smaller fraction of the beam is effective in irradiation of a cylindrical sample due to edge loss effects.

A more complicated system for obtaining complete irradiation of a cylindrical sample without rotation has been developed in the USSR (Figure 7). The deflection magnet (1) deflects the beam into three beam tubes each of which passes through a further magnet (2, 3 and 4) which are designed to direct a portion of the beam on to one third of the circumference of the sample. This system allows the treatment of a large diameter (e.g. 15 cm) sample - to a depth given by the one-sided irradiation conditions discussed above.

Beam Deflection and Throughput

For irradiation of a sheet, an electron beam can be easily deflected to provide a linear scan of length equal to or greater than the width of the sheet. Likewise, a two dimensional scan can be used to reduce the instantaneous beam power density in the sample. Beam deflection changes the angle at which electrons enter the sample and this reduces the effective depth by a $\cos\theta$ factor where θ is the scan angle. If the sample is moved away from the beam deflection system the scanned area is increased without the need to use large angles.

It is easy to produce an electron beam with a power of tens or even hundreds of kilowatts. The dose (Gray) is given by:

$$D(d) = 10^3 \, fF(d)P \, t / M \qquad (4)$$

where f is the fraction of P (electron beam power, watts) utilised;

F(d) is the ratio of dose at depth d to the average dose;

M/t is the mass per second irradiated.

As typical numbers, a 20 kW beam of 1.5 MeV electrons will deliver a dose of 1 kGy to 1 kg/s of material. This is quite impressive and indicates that a beam which is scanned to cover an area of the order of 1 m² is very useful for material irradiation.

Radioactivity

A quite different consideration affecting the choice of electron energy is that of the possible production of radioactivity in the sample itself or in neighbouring materials. Such radioactivity may be produced directly by photonuclear reactions or indirectly by neutrons emitted as a result of photonuclear reactions. A photonuclear reaction can only occur if the incident electron or photon has an energy which exceeds a threshold value which depends on the nuclide being irradiated. The four isotopes with the lowest threshold energies are listed in Table I.

A philosophical limit of 1.66 MeV can be set below which radioactivity cannot be produced. Below this energy an electron beam system is analogous to an x-ray set. Radiation is produced while the beam is on and is absent when the beam is turned off. In the present climate of concern about radiation, operation below 1.66 MeV can give a public relations advantage.

None of the reactions listed in Table I give rise to radioactive nuclides so that radioactivity can only be produced by secondary neutron interactions. To illustrate this situation, development of sensitive methods for the assay of beryllium or deuterium provide interesting examples. By placing rock samples for one hour in a 2.15 MeV, 1 mA electron beam, Guinn and Lukens (2) were able to detect the radioactivity in 1 litre of manganese nitrate placed nearby when 1 ppm of beryllium was present in the sample. A similar irradiation with a 3.0 MeV electron beam allowed detection of the deuterium component of 0.05% hydrogen.

The neutron yield is very low until the incident energy is well above threshold and can be strongly reduced by the use of suitable shielding materials. The probability of causing activation is also very low and the concentration or abundance of the isotopes involved are low. All these factors ensure that problems with activation are trivial for electron energies up to 2 or 3 MeV.

Table I

Photonuclear Reactions

TARGET ISOTOPE	ABUNDANCE %	CONCENTRATIONS (ORGANIC MATERIALS)	REACTION	PRODUCT ISOTOPE	THRESHOLD ENERGY (MeV)
^{9}Be	100	very low	(γ,n)	^{4}He	1.665
^{2}H	0.015	H = 5-10%	(γ,n)	^{1}H	2.223
^{17}O	0.037	O = 20-30%	(γ,n)	^{16}O	4.142
^{13}C	1.11	C = 40-50%	(γ,n)	^{12}C	4.946

Optimum Parameters

The optimum energy involves consideration of the following trends in the context of a specific application:

(a) the usable thickness of product increases linearly with electron energy;

(b) the variation in dose through the product increases rapidly up to 1 MeV and only slowly above this energy;

(c) the fraction of the electron energy which is utilised is approximately constant above 1 MeV (60% for one-sided and 80% for two-sided irradiation);

(d) the production of radioactivity is theoretically impossible below 1.66 MeV and of no practical significance up to well above 2 MeV; it will become increasingly important at higher energies;

(e) the dose delivered is a linear function of beam power; if the total current is limited then a higher voltage makes possible a higher throughput;

(f) for a specific accelerator design it is often cheaper to obtain a higher beam current rather than a higher energy;

(g) single stage or direct accelerators are usually cheaper and more efficient than multi-stage r.f. accelerators but are limited to voltages below 3-5 MeV.

The usable thickness is a major limitation making it necessary to use high energies (e.g. 10 MeV) and possibly electron/x-ray conversion for the irradiation of large objects. Low energies are suitable for irradiation of some types of material such as thin sheets, wires, sheet surfaces and, in the case of food, grain. For these applications the energy can be selected to match the thickness to be irradiated, up to 2-3 cm at 3-5 MeV. If public relations problems are serious an energy below 2.2 MeV or even below 1.66 MeV may be preferable.

PRACTICAL SYSTEMS

A low energy electron irradiation system for use in the disinfestation of grain has been developed in the USSR (3) and has been in use at the port of Odessa for approximately 5 years. Since this is the main example of commercial use of low energy electrons it is the basis of the following description with additional information on possible alternatives.

Accelerators

Electrostatic accelerators are available to produce voltages up to 20 MV but the maximum current is generally quite restricted above 3 to 4 MV. Even at lower voltages the maximum power is limited to the order of 1 kW so that these machines have limited usefulness in electron irradiation - especially of bulky food products. The most useful low energy accelerators are those based on A.C. power supplies - either at low frequencies (e.g. 400 Hz) or at radio frequencies (e.g. 100 kHz).

A number of circuit designs have been used in low frequency, insulated transformer, accelerators and their characteristics are summarised in Table II.

Table II

Typical Low Voltage Electron Accelerator Parameters

TYPE	COUNTRY	MAX VOLTAGE	MAX CURRENT	POWER
Electrostatic				
Van de Graaff	USA	3 MV	0.5 mA	1.5 kW
Low Frequency				
Insulating Core Transformer	USA	1 MV	50 mA	50 kW
		2.5 MV	15 mA	37.5 kW
Cockroft-Walton	JAPAN	2 MV	30 mA	60 kW
Insulated Secondary Transformer				
(ELV 2)	USSR	1.5 MV	13 mA	20 kW
(ELV 4)	USSR	1.5 MV	26 mA	40 kW
High Frequency				
Dynamitron	USA	1.5 MV	100 mA	150 kW
		2 MV	100 mA	200 kW
		4 MV	50 mA	200 kW

Other types and models have also been developed. An important feature of the low frequency systems is that they can achieve 70-80% efficiency in conversion of electrical power to electron beam power. This can be compared with an efficiency of 20% or less for the multi-gap linear accelerators which are used for energies above 5 MeV.

A schematic illustration of a typical low frequency accelerator is shown in Figure 8.

The power supply is operated within a pressure tank containing SF_6 insulating gas and an electron gun and beam tube are mounted in the centre. In order to maintain good focus the beam tube consists of many sections which are connected to successive stages in the diode/capacitor network which converts the transformer output to D.C. voltage. For 1.5 MV the beam tube is approximately 1.2 m long and the pressure tank is 2 m long and 1 m diameter.

The beam tube is continued through the base of the pressure tank where vacuum pumps and a beam scanner are mounted. Two dimensional beam scanning is produced by the magnetic fields from two sets of coils placed close to the beam tube and at right angles to each other. The current in each set of coils is provided by a sawtooth current generator so that the deflected beam moves across the sample at a uniform speed. Scan frequencies from 50 Hz to 1 kHz are used to ensure that each part of a moving product stream is exposed to the beam for the same length of time. However, the current density at the product is given by $I_o \cos\theta$ where I_o is the current density at the undeflected position and θ is the angle of deflection. The variation can be kept to ± 10% or less by choosing the distance from the scan coils to the sample so that a maximum deflection angle of 25° is sufficient.

A triangular metal vacuum chamber is used following the scan coils and the end of this chamber is closed by a thin metal window through which the electron beam can pass without losing much energy. The foil is mounted as part of a cylinder in shape to give it maximum strength and air from a blower is directed across the outer surface of the foil to keep it cool. The curvature of the foil will introduce variations into the electron energy loss but these are quite small. A second, thinner aluminium window can be used if necessary to protect the main vacuum window from the abrasive effects of dust.

The accelerator and scanning chamber can be mounted either vertically or horizontally, depending on whether a horizontal or vertical product stream is to be irradiated. Some accelerators have a separate tank for the high voltage supply which is mounted at right angles to the beam tube system. An air gap of approximately 10 cm is acceptable between the exit window and product stream.

Product Handling

A high power electron beam can be used for the disinfestation of a least 200 tonnes of grain per hour provided that a high speed stream is used (4). The system in use at Odessa is shown in Figure 9. It is based on the use of gravity feed to direct the grain through an electron beam at a speed of approximately 6 m/s. A 600 t hopper at a height of approximately 25 m is used to supply grain to an irradiator chute. A filtering screen removes foreign matter and an adjustable parallel gate is used to create a stream which is 1.5 m wide and has the required thickness (e.g. 7 to 9 mm). A second fixed gate is located towards the bottom of the chute to ensure that grain flow is not excessive.

At the bottom, the chute curves under the vertical electron beam and the centrifugal forces keep the grain in a well-defined stream away from the titanium window. After passing through the approximately 8 cm wide electron beam the grain passes into a receiving hopper from which it is directed out of the facility for re-irradiation. A fast-acting gate redirects the exiting grain back to the feed hopper if electron beam sensors at the extremities of the scan horn indicate that the beam current or scanning width do not have the required values. Suction pumps are connected to the chute just after the irradiation chamber to remove dust, ozone and nitrogen oxides (the latter being produced by electron irradiation of air).

The curved outer portion of the chute is water cooled to take away the heat deposited by the electron beam. It wears from the abrasive effects of grain and dust and must be periodically replaced. There is no significant rise in temperature of the grain stream since the energy deposited is only of the order of 0.4 J per grain. Turbulence in the grain flow causes individual grains to rotate and this improves the uniformity of dose received which is set to always exceed 0.2 kGy. Many factors contribute to dose variations, including:

(a) variations in beam power and geometry;
(b) variations in grain speed and rotation;
(c) the dose distribution (section 1.2);
(d) the presence of foreign matter.

The combined effects may lead to the maximum dose being up to twice the minimum dose.

Some experiments have been carried out with a horizontal accelerator and vertical grain stream but this approach has not yet been developed for routine operation. The use of a vertical electron beam and horizontal grain conveyor is also feasible provided that beam scanning, beam power and grain speed are chosen to obtain the required dose and throughput. In all cases, a considerable amount of power is needed for grain handling, equipment cooling and exhaust systems and other auxiliary equipment so that the overall power efficiency is much less than the 70-80% for the accelerator alone. Large products, which require surface irradiation only, could also be treated by an electron beam if a beam geometry such as that in Figure 6 is coupled with appropriate product rotation to ensure a uniform dose distribution. Such a system has not yet been developed.

Safety and Shielding

X-rays are generated when the electron beam strikes the exit window, air, product and the chute lining behind the product stream. The x-ray energy and intensity increase as the atomic number of the irradiated material is increased so that the shielding requirements will be maximum if the beam reaches the chute lining without passing through any grain . Most shielding is therefore required around the irradiation area and lead lined concrete thickness of the order of 1 m is likely to be needed for a 20 kW electron beam. However, some x-ray production also occurs within the accelerator and x-rays from the irradiation area can be scattered by accelerator components. Shielding of the accelerator is thus also necessary and re-entrant ports are needed for product entry and exit.

All radiation is removed when the electron beam is turned off and, for energies below 1.6 MeV, immediate access is possible to all parts of the accelerator and irradiation facility. Access to radiation areas can be interlocked with accelerator controls and fixed monitors can also be incorporated in the interlock system to ensure there is no exposure of personnel to radiation. Other necessary safety measures include the removal and treatment of room air and exhaust gases to prevent exposure to ozone or nitrogen oxides as well as normal practice to prevent electrical or mechanical damage to equipment or personnel. In effect, safety procedures are similar to those for any industrial or medical x-ray unit. For beam energies above 1.6 MeV consideration must also be given to protection against possible production of radioactivity.

Operation and Maintenance

For a research facility, it is necessary to be able to separately control accelerator voltage, electron gun parameters, beam current and scanning parameters. In a production facility, these would be preset and stabilised to required values and a data logger used to monitor correct performance and any fault occurrence. Push-button operation of a fully automated irradiation facility could be readily incorporated into a grain handling control system.

Once the accelerator has been outgassed, a rise in vacuum level is a sign that the exit window has been slightly damaged and should be replaced. The average life of a window is of the order of 1000-3000 hours of operation and the electron gun filament also needs to be replaced at a similar frequency.

Other component lifetimes should be at least 10000 hours of operation. Changes to equipment inside the accelerator tank require removal of the SF_6 gas and removal of part of the tank and inner components. This can usually be completed within one shift. Both down-time and costs for maintenance of a low frequency accelerator are quite low but they tend to be higher for r.f. accelerators.

PERFORMANCE

Disinfestation

Extensive research has been carried out into the effects of electron and gamma radiation on the various stages of insect development. The most common species associated with wheat are sterilised by a dose of 0.2 kGy and 100% mortality is observed after a period of approximately 30 days. Some species may require a dose of up to 0.4 kGy to achieve this effect. The Odessa facility is operated to provide a mean dose of 0.25 kGy and measurements of dose show that this can vary from 0.2 kGy up to possibly 0.4 kGy. These conditions have been shown to be completely effective for the disinfestation of wheat involving fifteen species of insects. Barley, maize and sorghum have also been successfully treated in the same system. The effects of irradiation on the quality of grain products do not seem to pose a problem but further investigation of this aspect may be necessary, especially for other types of grain such as rice.

Costs

The cost of a facility will depend on the performance required but is of the order of 1 to 2 M$ for a 20 to 40 kW accelerator at 1.5 MeV. Amortization of this capital expenditure is the largest contribution to disinfestation costs which have been estimated to be less than $1 per tonne. It is likely to be cheaper to use a higher power accelerator to treat more grain rather than to instal several accelerators. However, the second approach offers more versatility in operation since one unit can be operated while maintenance or development is carried out on the other. Since maintenance is only necessary a few times per year it should not be an important limitation. For routine application, the logistics of grain handling, irradiation and storage require careful attention.

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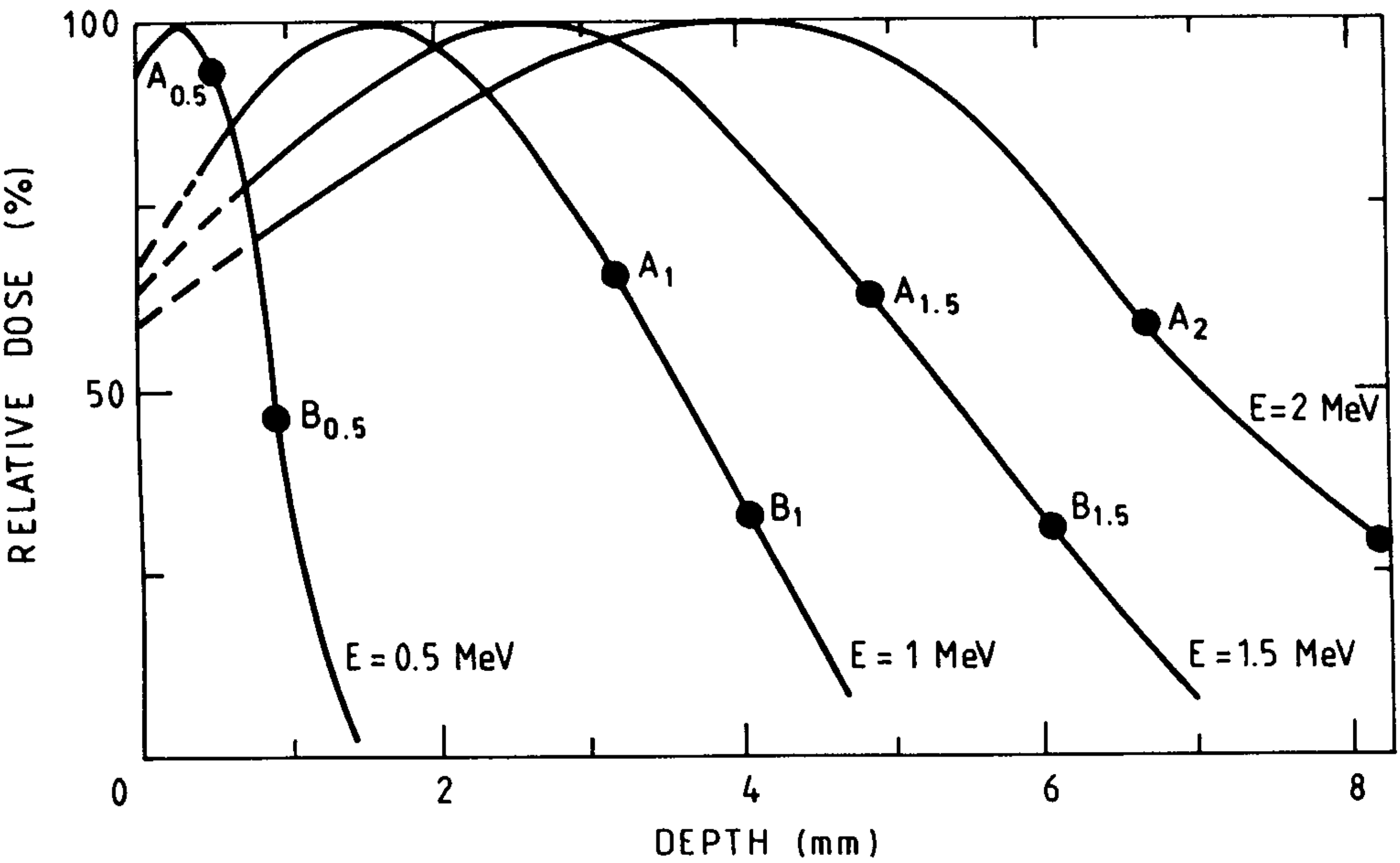

Figure 1 The relative variation in dose with depth of penetration for various electron energies from 0.5 to 2.0 MeV. The points marked A show the depth at which the dose drops to the same as that at the surface. The B points are for one-half of the surface dose.

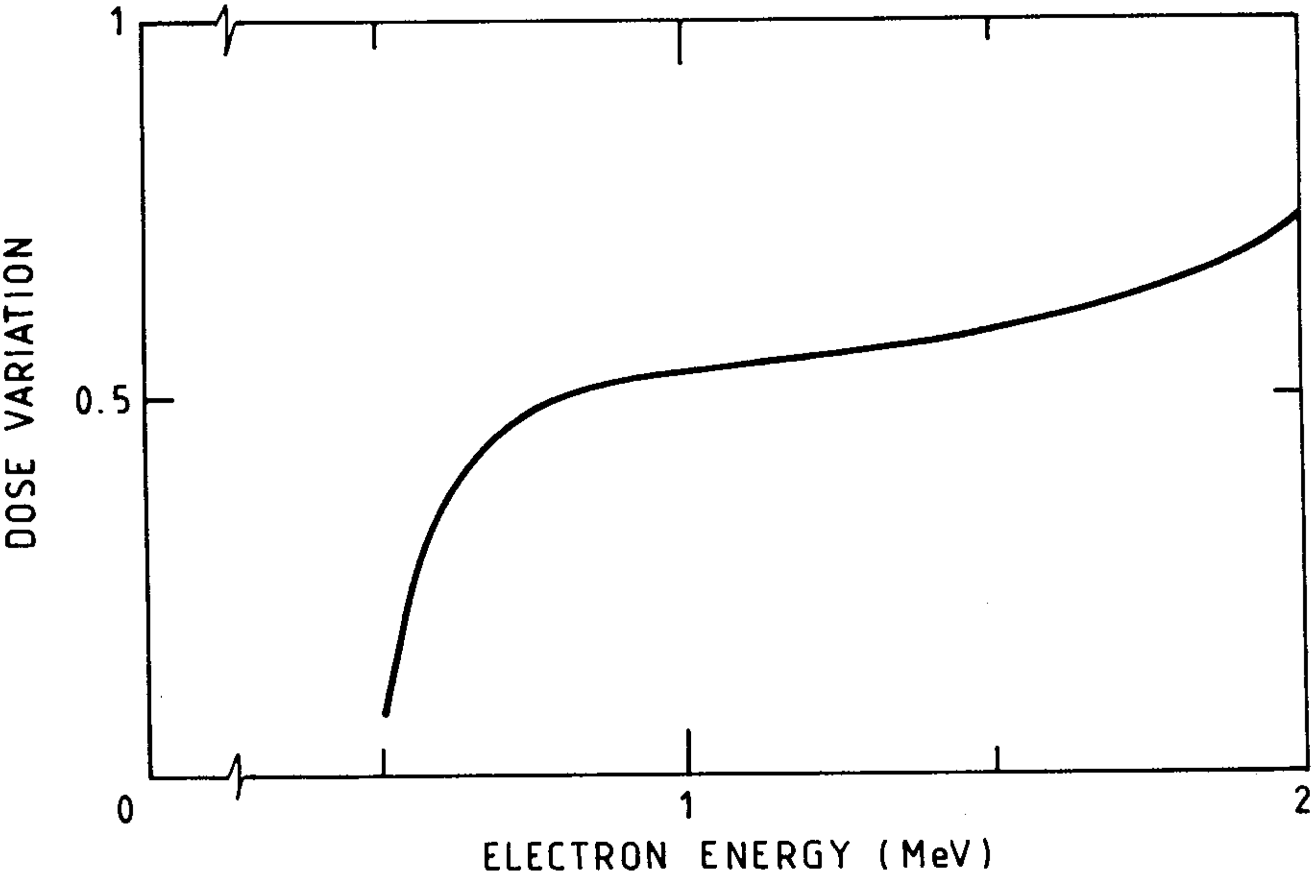

Figure 2 The variation in dose $((D_{MAX}-D_{MIN})/D_{MIN})$ as a function of incident electron energy for exit dose equal to surface dose

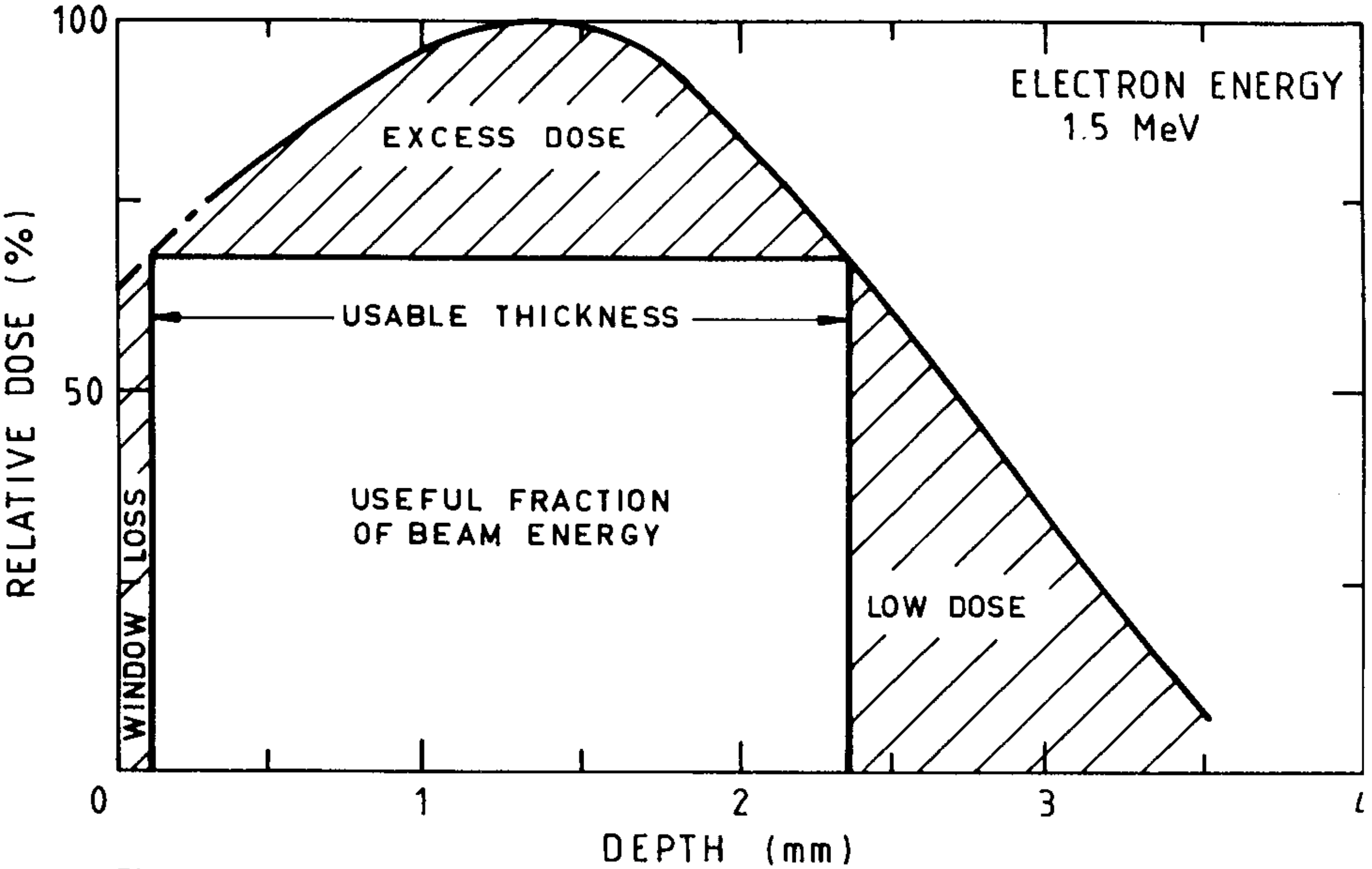

Figure 3 The dose distribution curve for 1.5 MeV incident electrons, showing the fraction of dose lost due to energy loss in window and air gap (left), electron penetration beyond the usable sample thickness (right) and the excess dose above that required to achieve a specific effect.

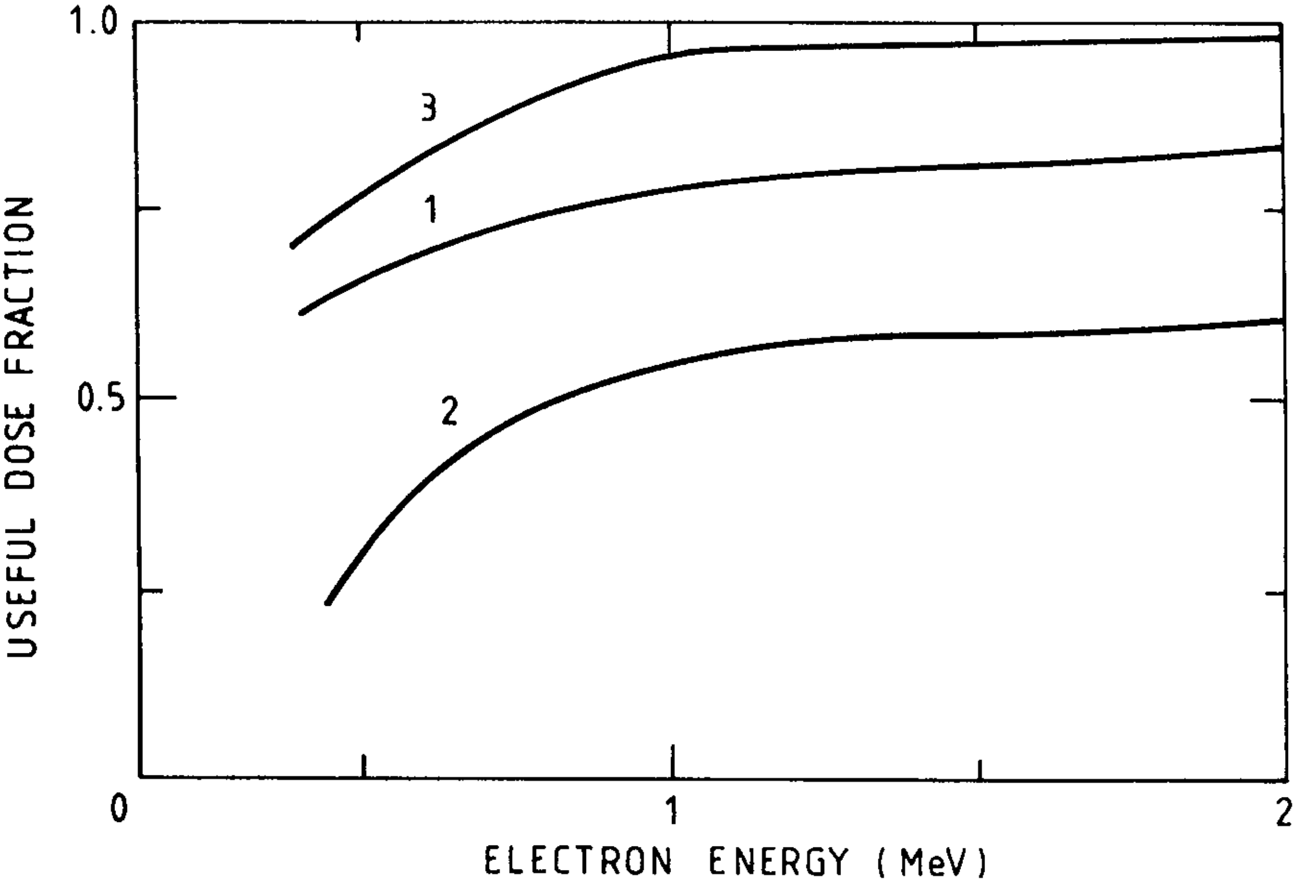

Figure 4 The variation in useful dose fraction as a function of incident electron energy; curve 1 is for a one-sided irradiation allowing for window and low dose effects only; curve 2 includes the effects of excess dose; curve 3 is the same as curve 1, but for two-sided irradiation.

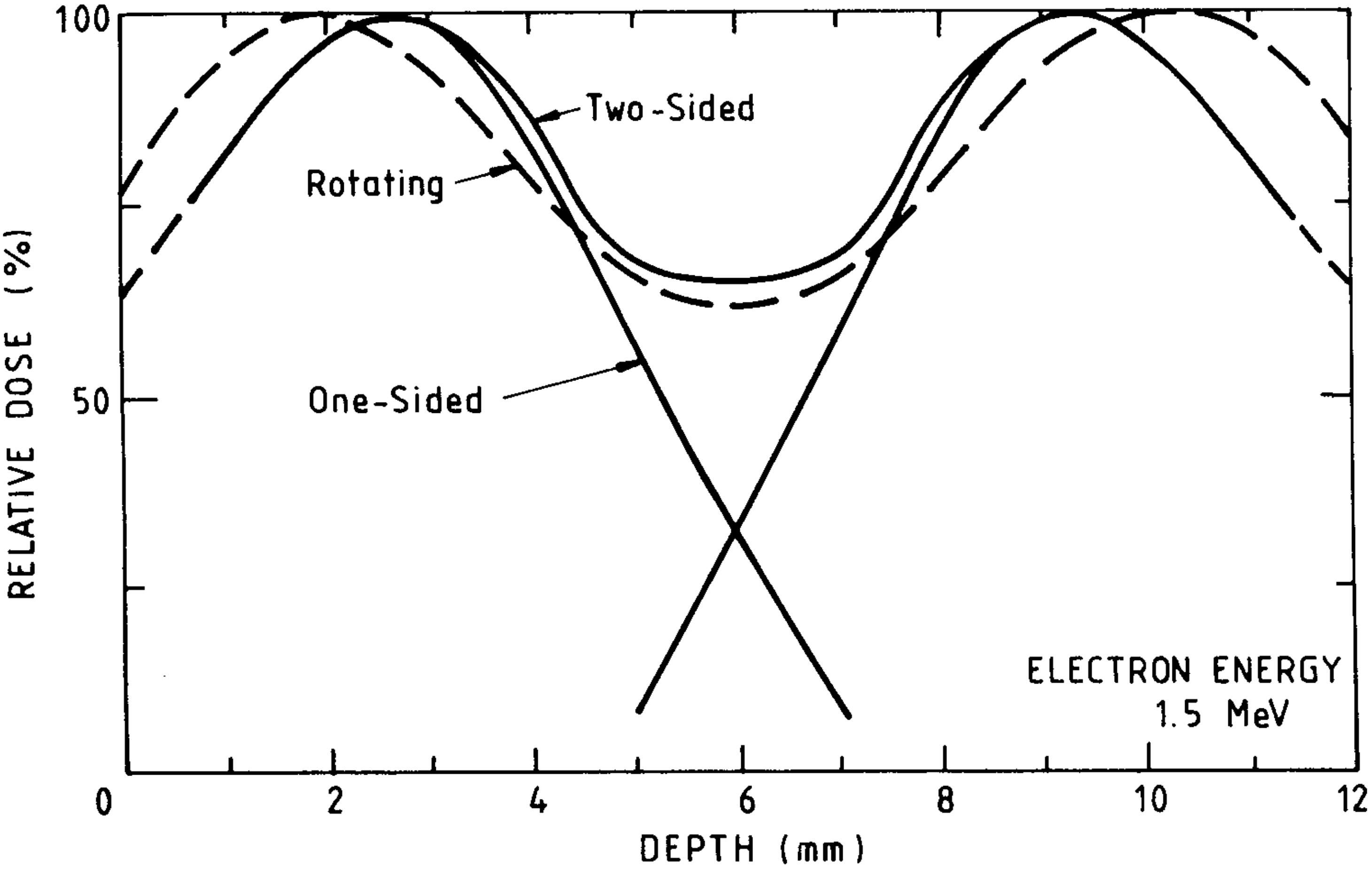

Figure 5 The relative dose distribution for 1.5 MeV electron irradiation using one-sided or two-sided irradiation or a rotating sample.

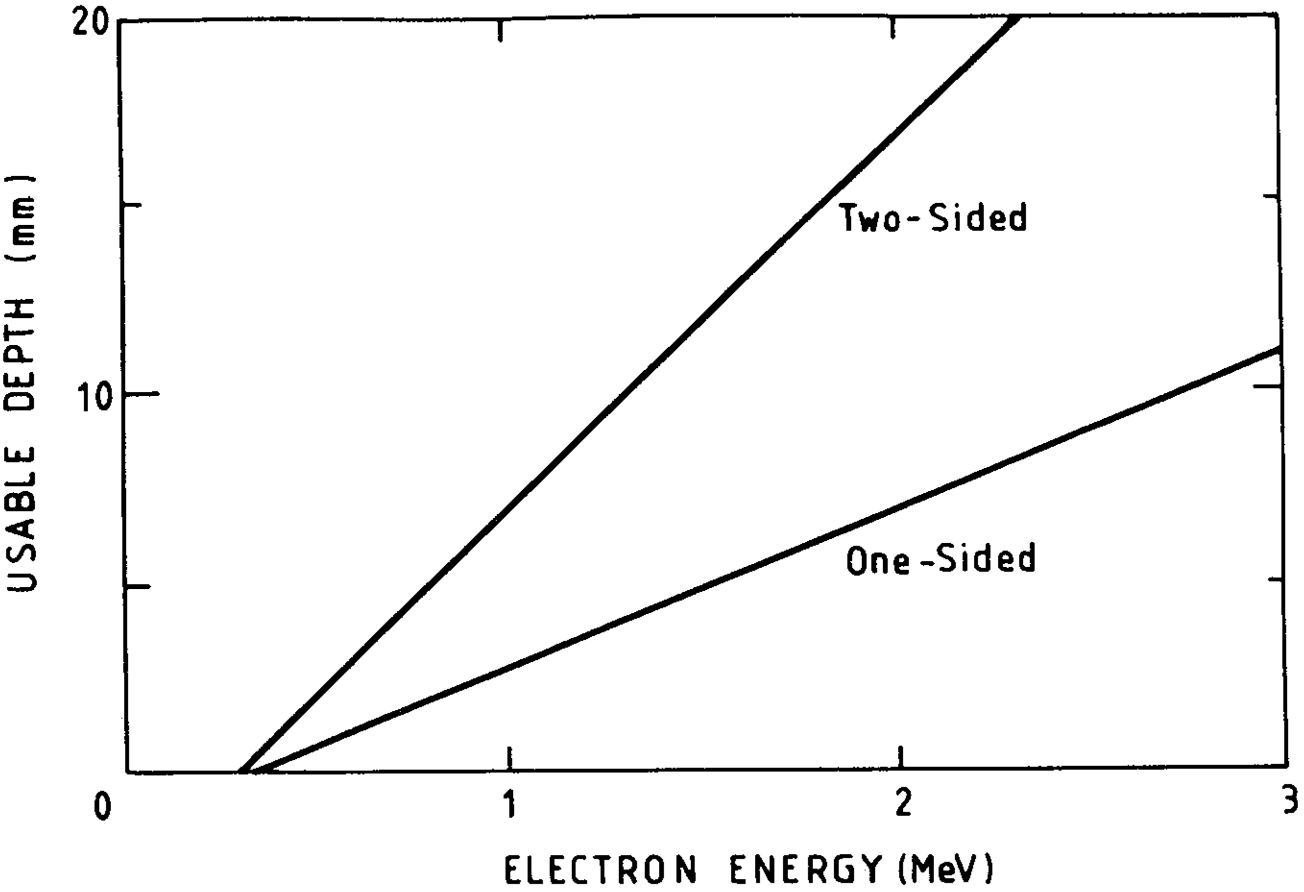

Figure 6 The dependence of usable depth of irradiation (exit dose = surface dose) as a function of electron energy for one-sided and two-sided irradiation.

1. Switching magnet
2. Scanning magnet
3. Deflection magnet
4. Exit window
5. Sample

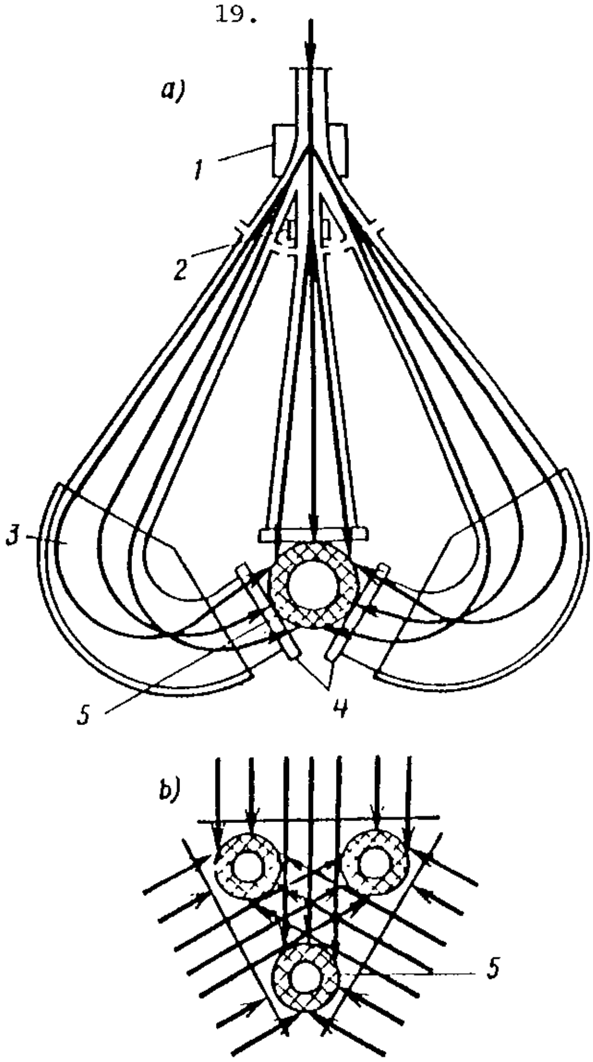

Figure 7 Schematic diagram of device for three-sided irradiation of cylindrical samples: (a) one sample; (b) 3 samples.

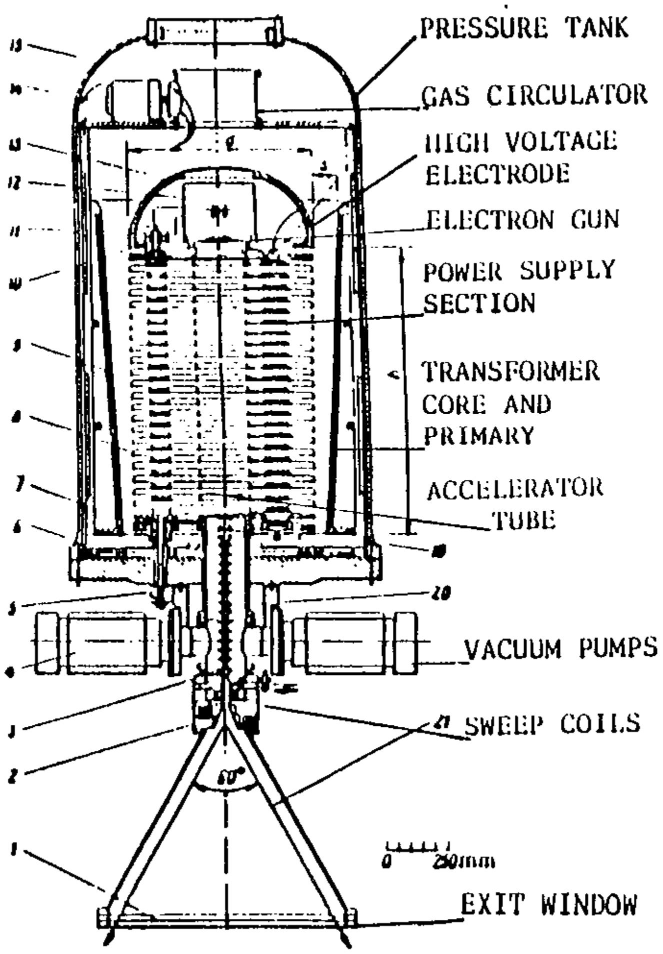

Figure 8 Layout of components of the 1.5 MeV ELV-2 electron accelerator and scanning system (3).

1. Electron accelerator
2. Level sensors
3. Feed hopper
4. Flow-forming gate
5. High-speed gate
6. Spread chamber
7. Dispersion channel
8. Deflection plate
9. Water cooling
10. Bucket chain
11. Level sensors
12. Suction chamber
13. Output hopper
14. Diversion chamber
15. Diversion gate
16. Grain level control

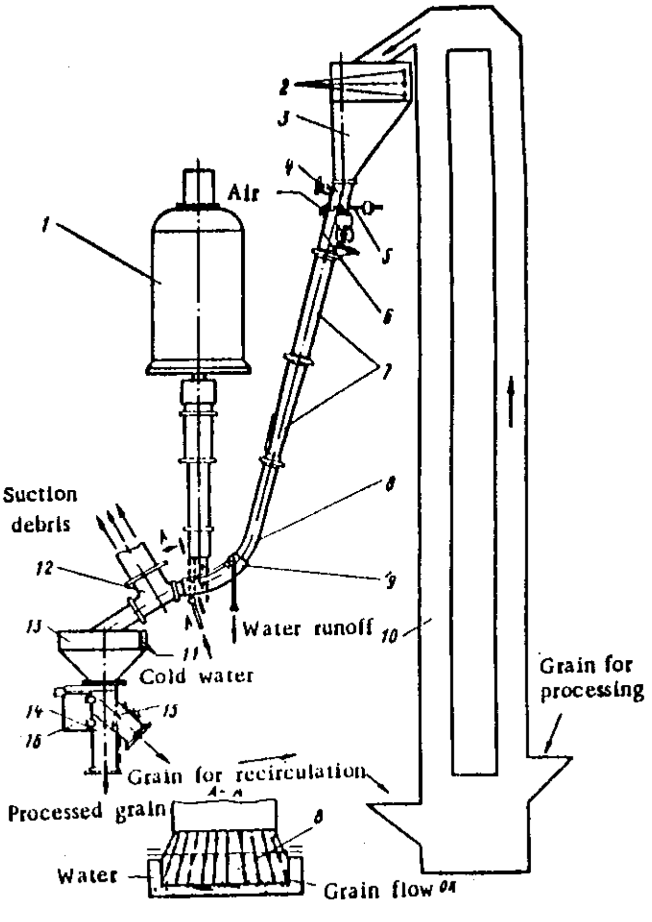

Figure 9 Schematic diagram of 1.5 MeV electron accelerator and grain irradiation system (4).

LECTURE 23

COBALT 60 COMMERCIAL IRRADIATION FACILITIES

G. WEST

COBALT 60 COMMERCIAL IRRADIATION FACILITIES

G. WEST

Let us first discuss where the Cobalt 60 comes from.

Cobalt as an element has an atomic weight of 59. The Cobalt is mined from the ground machined down into small pellet sizes and then placed into a nuclear reactor. The pellets of Cobalt in the reactor are bombarded by neutrons, and eventually pick up an extra neutron into the nucleus of the Cobalt atom. This increases the atomic weight to 60, and the Cobalt is now Cobalt 60. However, the other neutrons and protons in the nucleus of the atom are not too happy about this intruder, and they set up a reaction to try and get rid of it, this reaction is in the form of Gamma and Beta rays. It should be understood that the Gamma rays that are emitted are deeply penetrating, but have insufficient energy to break into the nucleus of an atom. Thus Cobalt 60 cannot impart radio-activity to any substances exposed to it. The now radio-active Cobalt 60 slugs are removed from the reactor and encapsulated into stainless steel pencils. These pencils are approximately 18" long and ½" in diameter. The slug is double sheathed in stainless steel to ensure that it cannot under any circumstances be removed from the encapsulated pencil. The pencils are then placed into a source module, each module contains 22 source pencils. The modules are then arranged in a source rack. The size and configuration of the source rack differs for different types of applications.

The advantages of using Cobalt 60 for ionizing treatment are, that it has excellent penetration, in fact it takes up to 6' of concrete to stop the gamma rays omitted from a 2 million curie source. Gamma Plants are also very efficient, in as much as there is very little mechanical or electrical equipment involved or incorporated in a gamma irradiation facility, compared to that say of an electron accelerator machine, therefore there is less that can go wrong and the average efficiency of a gamma plant is usually around 95% of all available processing time. This advantage of course becomes critical when processing perishable goods. It would be a disaster if half way through processing a shipment of frozen prawns for example, the plant was to break down and not be able to resume production for a number of hours.

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There are of course disadvantages to using Cobalt 60. The major disadvantages are, Cobalt 60 is constantly decaying it loses its strength and therefore its throughput capabilities by 13% per annum. This decay is non-negotiable and occurs whether the Cobalt is being used or not. Another major disadvantage is that, at present there is really only one major supplier of Cobalt 60 in the world. That supplier is the Atomic Energy of Canada Ltd. This disadvantage has become very apparent over the last twelve months, as there has been an acute shortage of Cobalt 60, so much so that A.E.C.L. had all customers on an allocation system. This of course is not good for business. The last major disadvantage, and probably the greatest, is the fact that Cobalt 60 is a member of the nuclear family and no matter whether we call it irradiation, ionization, picowaves or whatever, there is no getting away from the fact that users of Cobalt 60 will be lined up with the nuclear industry, and as this is such an emotive issue these days no-one escapes from the stigma of Three Mile Island.

Let us now examine step by step the procedures that need to be carried out before a gamma irradiation plantcan become fully operational. The first action that needs to be taken, it to gather market intelligence or to determine the specific needs that a plant would service. This would include what products would be required to be processed and at what dose, making sure that the minimum and maximum dose was clearly defined. What size of units would the products be processed in, that is what are the size of the shippers and cartons to be used. We must then determine when they will be processed, some produce are seasonal and the demand on the plant may be subject to these seasonal variances. What quantity of product can we expect, this is probably the most important variance of all. Then we must decide where the plant will be located, this will influence the initial cost of purchasing land. We must also decide what size of land will be required, and it is at this stage that a decision must be made on how much warehousing you will have on your site.

Having gathered this initial market intelligence, you can now move on to the second step in the project, that being that you can now decide on what type and size of plant that would be required.

There are two different types of plant design available. Both are similar in that they have a concrete shielding, a source pool to store the isotopes in when they are not being used, and the filtrating and de-ionizing systems are also identical. Where they differ, is in the method of moving the product through the source chamber. There are two different types of plants, a tote box plant and carrier plant. The tote box plant as its name suggest moves the product through in an aluminium box, whilst the carrier plant moves the product through in a long carrier suspended from the roof on a monorail. The tote box plant has greater cobalt efficiency and much better dose uniformity throughout the product. However, the plant is very inflexible and suited to a one dose application only, that is for instance processing medical products to a level of 25 k/grays consistently. The size of package or outer shipper that can be processed is limited to the size of tote box that is used, and this plant is therefore ideal for someone who has a captive product, that is an in-house application where they are only processing their own products, they can therefore control the size of shippers used. However, for a contract service facility a much more flexible approach is required and it is in this area that the carrier plant has become very popular.

Carrier plants like the tote box plants come in various sizes, from carriers 7' high to carriers 12' high that can contain or process full pallet loads of product. Although the carrier plant is not as Cobalt efficient as the tote box plant, it does give greater flexibility. Any contract facility offering the ionizing service must be expected to receive the products to be processed in any shape or size of weight. Although an ongoing effort is maintained to try and educate customers into using shipper sizes that will fit into the tote box or carrier exactly, most customers have their own idea of what size of outer shipper they will use. This is usually determined by the quantity of products that they are selling in each shipper. The carrier being much larger gives a greater flexibility for size of containers or shipper that can be processed. Also by the use of an incremental dose accumulation system, each individual carriers exposure time can be controlled, thus enabling each carrier to receive a different dose. Ansell International have both types of plants. In Melbourne and Malaysia we have the tote box irradiators, whilst our new plant which will come-on-stream in November this year, is a carrier plant.

Getting back to our market intelligence, we can determine what type of plant will need to be constructed to suit that specific application. For example, if the vast majority of product to be processed is medical products at 25 k/gray, then a tote box irradiator could be the type of plant that should be constructed. However, if there is a variety of products to be processed at a large variety of different dose levels, then it is obvious that the carrier plant would be the favoured facility to construct.

Again, referring back to our market intelligence data and by specifically looking at the size or volume of product and quantity of products that will be required to be processed, we can determine the size of plant that will be required, for example a one million, or a two million or even maybe a five million curie capacity facility.

Having decided on the size and type of plant that will be needed we must now come up with a cost. Let us look at the economic requirements. These fall into two areas, Capital items and Operating costs. The capital items are costs that will be initially incurred into constructing the plant. The operating costs are ongoing costs that must be met in order to process the products. Capital items would include the cost of land, the cost of an irradiation chamber and equipment, the cost of warehousing, the cost of administration offices, the cost of laboratories, the initial Cobalt 60 loading, the cost of plantand equipment such as forklift,trucks, conveyors, compressors, computers etc.etc. When all of these expenses have been totalled up, then that final figure will be the initial payout required to enable the project to go ahead. Operating costs must now be calculated, these include depreciation of plant and equipment, that is all the capital items mentioned before have depreciated over a certain amount of years. This depreciation time varies from item to item and is usually determined by corporate accounting policy. Other operating costs that need to be calculated are people costs, that is wages for indirect and direct employees, you must also add in the overhead costs such as overtime payment, payment set aside for sickness, payment set aside for tax etc.etc. Another major operating cost is Cobalt replenishment, as mentioned before the Cobalt is decaying at 13% per annum and an allowance must be made in your operating costs to cover the purchase of future Cobalt in order to maintain your throughput capabilities.

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There are other minor costs which go on an on, such as maintenance equipment, security, stationery, training costs, site charges such as telephones, power, water, rates and taxes as well as many many minor costs, including waste disposal, cleaning and protective clothing.

Over the years, Ansell have become very proficient at containing most of these costs, but that is something that only experience can teach you.

Having determined the cost to operate and pay for the plant and knowing the expected throughput, you can then determine the break-even minimum charge for processing products through the plant. If you wish to make a profit, then a profit margin is added to give the operating profit before tax (O.P.B.T or G.P.). It's at this stage that any sales and marketing expenses are deducted, for instance promotions,advertising any sales staff costs, brochures, travel or entertainment expenses. The marketing expenses are then deducted from the operating profit before tax figure thus giving a marketing profit. This is the bottom line, and it will show very quickly whether a construction and operation of a gamma irradiation facility is economically feasible or not.

Assuming the figures come out right, and funding is granted the next stage in the operation is to immediately take up an option on land purchase and it is at this point, that all regulatory authorities should be contacted and given a detailed specification of the facility that you wish to construct. The regulatory authorities will evaluate the specification and inform you if it meets the licencing requirements or not. Once approval has been received from the regulatory authorities, an application to develop the facility must be lodged with the local municipal council. The council will evaluate the application and once that they are satisfied that the plant is not a potential hazard to the safety, health and welfare of the municipalities residents, then the application for development will be approved. This part of the whole project is the most exhaustive and difficult part to complete. The local municipal council is made of residents from that area, these people are not physicists and have no experience of the ionizing energy process. They have been influenced by all the adverse publicity that has been given to nuclear power, including nuclear weapons over the years.

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It has therefore, been our experience that a great deal of careful education is required before the council members overcome their fears and suspicions. There are many pitfalls that can be fallen into during this phase of the project, and it is important that all facts and information regarding the application are given to the council members, and attempt to conceal any matter would be fatal at this time. Assuming the council is satisfied and deveopment application is approved a building approval must be given. This is usually carried out by local and state authorities and relates mainly to the construction design and materials used in the building of the facility.

The difficult part is now passed, and the next step is a normal construction project.Although nothing ever runs smoothly at least the problems that are met now are not unusual problems or problems that are specific to gamma plants, they are usually those problems associated with general construction work, and can be readily overcome.

Once the construction is well under way, it then becomes necessary to recruit and train personnel that will operate and manage the facility.Here it is advisable to co-ordinate with national and state authorities for advice. In N.S.W. we have been very fortunate in receiving sound advice from the radiation branch who have also offerred to conduct courses on occupational safety and health matters related to gamma irradiation plants. Special training will need to be given to the plant manager who will be the licensee of the facility, and he will need to demonstrate to the licencing authorities that he is fit and capable of being responsible for the facility. Training,of course,is also required in dosimetry processing, product handling, recording procedures and even in public relations and media contact.

The plant is then commissioned to ensure proper dose distribution and uniformity as well as all safety aspects are working perfectly. Once you have passed these inspections, you are now in the ionizing energy business, good luck!

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Ansell Internationals ionizing energy division have been in the contract service ionizing business for 40 years. The Melbourne facility was opened in 1971 and the Malaysian plant located in Melaka commenced operations in 1978. The brand new State of the Art carrier plant presently under construction here in Sydney, will be opened for business by the end of November this year. It is the divisions intentions to develop the business wherever there is an opportunity, and Ansell will be pursuing the expansion of its activities not only here in Australia, but throughout the Asian region. For example, a feasibility study is already underway for the construction of a plant in Queensland. Initial investigations are planned later this month for New Zealand. Further down the pipeline we see expansion in Malaysia and Thailand a distinct possibility.

During the last 14 years a great deal of experience and expertise has been gathered, commencing with the sterilizing of medical disposable products in the early days through to the present time where a wide range of products and applications are processed through the Ansell Plants. Some of the more unusual applications are, the processing of wine corks, beehive boxes, pharmaceutical raw materials, cosmetic powders, creams and gels. Agricultural peat soil, cut flowers for export, containers and plastic bags for fruit juices, tomato pastes, and dairy products. Feed stock for laboratory rats and mice, veterinary vaccines. The list goes on and on, and Ansell are constantly carrying out trials tests and research into the ionizing energy treatment of new products.

The company sees the treatment of food products by ionizing energy as the largest single growth potential for any of its products. We have already a list of potential customers who will begin to process food products as soon as approvals are received.

The company's success in constructing, operating and marketing a profitable gamma irradiation facility cannot be disputed and we would welcome the opportunity to work with any of the countries represented here to-day, with the mutual objective of establishing the commercialisation of the ionizing energy treatment of food.

Thank You.

GEORGE WEST
General Manager - Ionizing Energy Division.

LECTURE 24

COST CONSIDERATIONS FOR AN IONISING ENERGY TREATMENT FACILITY

R. CULPITT

COST CONSIDERATIONS FOR AN IONISING ENERGY TREATMENT FACILITY

Paper to be presented at an
International Workshop on the Commercialisation of
Ionising Energy Treatment of Food
held in Sydney commencing 29 April 1985

R.A. Culpitt,
Agricultural Economist,
Economic Services Branch,
Queensland Department of Primary Industries

APRIL 1985

COST CONSIDERATIONS FOR AN I.E.T. FACILITY

1. INTRODUCTION

It has been stated that the large number of variables influencing the calculation of costs of commercial food irradiation involves a complicated collection of assumptions and relationships. This makes a general discussion on costs difficult. Certainly, the evaluation of the commercial feasibility of a particular facility with a given throughput, product, dose, product density etc. would be reasonably straight forward and this is probably the reason why most research projects tend to be case study specific. The cost concepts that I intend to discuss are general concepts which could be related to any large food processing facility. I will attempt to relate them to the irradiation of food stuffs. The following presentation does not cover all aspects of the costs involved in commercial irradiation of foodstuffs but hopefully the main areas will be discussed in some detail.

2. VARIABLES INFLUENCING THE COST OF FOOD IRRADIATION

Variables influencing the cost of food irradiation can be included under three broad headings:

1. Variables concerned with the physical characteristics of products to be treated;

2. Variables concerned with the operational characteristics of the plant to be used;

3. Variables concerned with costs of establishment and operation of an IET plant.

2.1 Product characteristics

The variables relating to the physical characteristics of the products to be treated include:

1. Effective density of a product.
2. Dose - including minimum/maximum tolerance levels.
3. Temperature requirements during processing.
4. Packaging, degree of uniformity and storage requirements.
5. Product characteristics relating to irradiation effects on colour, odour or texture.

Irregularity of shape, size or density of items to be treated will reduce source efficiency and increase costs. The concept of source efficiency will be discussed later.

Irradiation costs will vary directly with dose levels required, with some variation depending upon the range of tolerance provided in the maximum-minimum allowable dosage which will again affect source efficiency.

Preservation of product characteristics relating to colour, taste and texture etc, also influence costs by requiring a controlled environment during processing particularly in regard to temperature.

Product handling requirements also influence the cost structure of a plant as they affect the storage requirements, container size and type, on-loading and off-loading equipment, and manpower requirements.

2.2 Plant characteristics

Variables concerned with plant characteristics include:

1. Type of irradiation
   - Radionuclide - source size, storage system, loading and raising systems;
   - Electron beam accelerator - type, kilowatt power, energy level.

2. Characteristics of products
   - size and shape of package;
   - throughput - annual, monthly, daily.

3. Movement of materials
   - internal/external conveyor system;
   - source dimensions;
   - number of passes.

4. Control systems
   - degree of automation;
   - dosimetry;
   - radiological protection and safety;
   - gas removal.

5. Efficiency
   - Radiation utilization factor;
   - Source efficiency factors.

6. Structural work
   - land and development;
   - structure for cell;
   - shielding;
   - storage facilities.

7. Location

In the case of radionuclide sources plant utilization is more important than capacity for any desired level of output. Consequently, when radionuclides are used, operations should be planned on a continuous operating basis to maximise capacity utilization and minimise cost per unit treated. The significance of a high plant utilization factor will be illustrated later.

2.3 Cost variables

The variables which determine total costs include:

1. Capital costs
   - depreciation
     - plant
     - radiation source;
   - interest on borrowed funds (opportunity cost of capital);
   - return on equity.

2. Operating costs
   - interest on working capital;
   - radionuclide reloading;
   - manpower;
   - repairs & maintenance;
   - plant utilisation factor;
   - power and other utilities.

Perhaps the most significant factor determining the commercial viability of a food irradiation plant is the amount of capital investment required to provide processing facilities at commercial levels. In order to estimate the probable costs of irradiating food at commercial levels I will now discuss what I consider to be the main determining factors.

3. DETERMINANTS OF FOOD IRRADIATION COSTS

The determination of total irradiation costs depends to a large extent on the cost of the energy source used, relative to annual throughput of product. Thus the selection of the type of source to be used will ultimately determine the nature of investment and operating costs incurred by an irradiation facility.

Comparative costs of alternative sources depend upon many factors including installed cost, efficiency of source utilisation, source reliability, and in the case of radionuclides the rate of replenishment. In the case of electron accelerators it is necessary to select the type of machine and energy level suitable for the products to be processed.

3.1 Source costs

The relationship that has been used to estimate the source requirements of any irradiation facility is:

One kilowatt (kW) of absorbed radiation power will treat 360 kg of food product per hour, with a density of one, at a 10 kGy dose at 100% efficiency of source utilisation.

o Source utilisation efficiency

The source utilisation efficiency factor is the ratio of irradiation energy absorbed in the product to the radiation energy emitted form the source. It takes account of the fact that not all the emitted irradiation energy is absorbed by the target material. The majority of the

energy emitted is absorbed by material other than the material being irradiated, e.g. packaging, conveyors, internal walls, etc.

As a result of these energy losses efficiency factors for radionuclides range from 20 to 40% for Cobalt-60 and 15 to 25% for Cesium-137 facilities. By comparison the efficiency factor for electron accelerator facilities may approach 50%.

- Capacity utilisation

As I will demonstrate later, total costs of a radionuclide facility are much less sensitive to changes in capacity utilisation than are electron accelerator systems. This is mainly due to the higher proportion of fixed costs incurred by radionuclide facilities, a large proportion of which is attributable to the cost of the source material.

The capacity utilisation is expressed as a percentage based on the number of hours per year, month or day that the facility is being utilised. For example, if a facility operates 8 hours per day it would be said to have a capacity utilisation factor of .33 or 33.3%, or if a plant was in operation 8000 hours per year, capacity utilisation would equal .916 or 91.6%.

It is the capacity utilisation factor that determines the quantity of throughput per unit of time that the facility will be designed to accommodate. For example, if a total annual throughput of say 64,000 tonnes is expected, and a capacity utilisation of 8000 hours per year is scheduled then 8 tonnes per hour of throughput will be possible.

o Source requirements (Radionuclide)

To illustrate the sensitivity of the various elements of the above relationship Table 1 has been constructed assuming a total annual throughput of 65,000 tonnes.

It can be seen from this table that for any given level of dose required and source efficiency, the initial curie requirement will vary directly with plant throughput per hour. The greater the throughput, the greater the source requirement. For any given level of throughput per hour the source requirement will vary directly with the dose level and inversely with the efficiency of source utilisation.

o Annual cost of radionuclide source material

Having established our radionuclide source requirement it is necessary to calculate the annual cost of that material. Unlike most items of plant and equipment radionuclide material requires periodic replenishment in order to maintain the level of radiation energy required by the facility. Thus, in addition to the initial investment in source material and the cost of capital and depreciation associated with that investment, subsequent smaller investments in replenishment source material is also required and these will also involve a depreciation and cost of capital expense. The problem of annual cost calculation is perhaps more critical when comparing the costs of the two radionuclide sources - Cesium-137 and Cobalt-60. This comparison is made difficult because of the different cost, curie requirement and decay factor for each source material. As you know Cobalt-60 decays at a

Table 1. Source requirement in million curies

Source efficiency	Average dose					
	1 kGy			2 kGy		
	Hours/year					
(%)	8000	6000	4000	8000	6000	4000
Cobalt-60						
15	1.00	1.35	2.03	2.03	2.71	4.06
20	.75	1.02	1.52	1.52	2.03	3.05
25	.61	.81	1.22	1.22	1.62	2.44
30	.51	.68	1.02	1.02	1.35	2.03
35	.44	.58	.87	.87	1.16	1.74
40	.38	.51	.76	.76	1.02	1.52
Cesium-137						
15	4.7	6.26	9.39	9.39	12.52	18.78
20	3.52	4.69	7.04	7.04	9.39	14.08
25	2.82	3.76	5.63	5.63	7.51	11.27

rate of approximately 12.5% per year while Cesium-137 decays at a rate of approximately 2.3% per year or about 11% every 5 years.

One method of calculating an annual cost of radionuclide source material would be to take a period of time, say 10 or 15 years, and to amortise the Net Present Value of the initial investment and the periodic replenishment costs. The nature of these cash flows is illustrated in diagram 1(a) and 1(b) for 10 year and 15 year time periods. These cash flows are based on the following assumptions regarding source costs, requirements, etc.:

(a) Installed price per curie - Cobalt-60 - $A1.50
Cesium-137 - $A0.40

(b) Source requirement in Curies - Cobalt-60 - 2M Curies
Cesium-137 - 14M Curies

(c) Salvage value of source material - 70% of initial investment.

The estimation of the salvage value of the source material is a difficult question. As this technology has not yet been fully developed the rate of obsolescence is much higher than for more developed technologies. As a source is replenished the unit strength and value of its components decline. Source design is subject to continuous technological improvments. There is no assurance of a market for discarded sources, indeed, problems of disposal involving expense could be encountered. The salvage value should take account of the rate of obsolesence of the source including replenishments, changes in source configuration, and values and problems relating to disposal of abandoned sources, etc.

The Net Present Values of the cash flows illustrated in diagrams 1(a) and 1(b) are calculated using the following formula

$$\text{Net present value - } NPV_{CFi} = \sum_{i=0}^{n} \frac{CF_1}{(1 + r)^n}$$

where CF_i = annual net cash flows
n = number of periods (10 and 15 years)
r = the discount factor (10%)

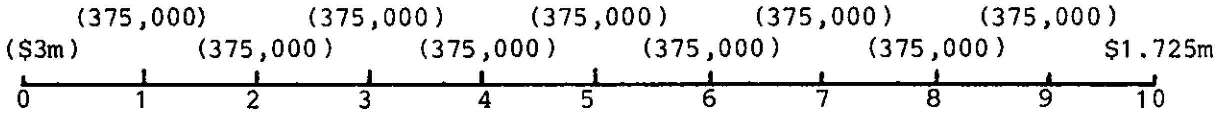
(The magnitude of the discount factor will be discussed later.)

The Net Present Value of these cash flows are:

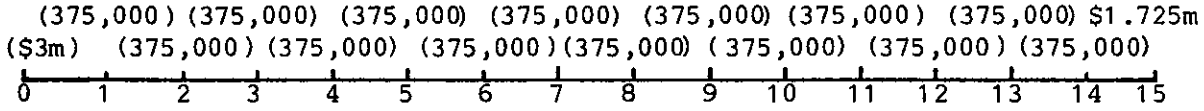
	$A
Cobalt-60 (10 years)	4,495,000
Cesium-137 (10 years)	4,709,000
Cobalt-60 (15 years)	5,350,000
Cesium-137 (15 years)	5,429,000

Having calculated the net present values of these cash flows it is a simple matter to convert them into annual equivalents. This is achieved using the following formula:

$$\begin{array}{c}\text{Annual}\\ \text{Equivalent}\end{array} = \frac{NPV_{CFi}\,[r\ (1 + r)^n]}{[(1 + r)^n - 1]}$$

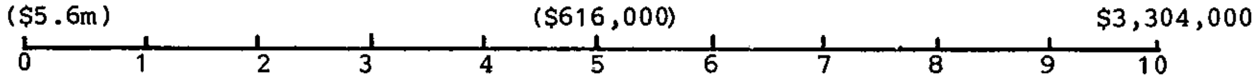


NPV = $4.495m Annual equivalent = $731,540

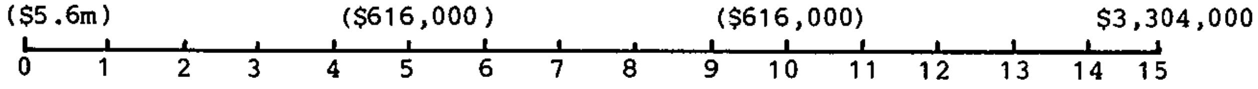


NPV = $5.35m Annual equivalent = $703,380

DIAGRAM 1(a): Cobalt-60



NPV = $4.709m Annual equivalent = $766,370



NPV = $5.429 Annual equivalent = $713,770

DIAGRAM 1(b): Cesium-137

The annual equivalent source costs are:

	$A
Cobalt-60 (10 years)	731,540
Cesium-137 (10 years)	766,370
Cobalt-60 (15 years)	703,380
Cesium-137 (15 years)	713,770

We are now able to compare the relative costs of each source material. The cost advantage as indicated by the above comparison in favour of Cobalt-60 is by in large a function of the higher energy output and the higher source efficiency of Cobalt-60. The low gamma-ray energy of Cesium-137 which produces considerable absorption of the radiation within the source itself and its encapsulation, contributes to its poor efficiency rating. If it was technically possible to improve the source efficiency of the Cesium-137 facility, from say a factor of .20 to .25 the source requirement would be reduced to 11 million curies of Cesium-137 as opposed to 14 million curries required in the previous exercise. This increase in source efficiency of the Cesium plant would result in the following annual equivalent source costs:

	$A
Cesium-137 (10 years)	602,100
Cesium-137 (15 years)	560,870

Consequently a 25% increase in Cesium source efficiency resulted in a 21% reduction in source costs on an annual equivalent basis. A cost/benefit appraisal would be required to ascertain whether the additional costs incurred in increasing source efficiency would be offset by the reduction in source costs.

o Dose

As indicated earlier in this paper the dose level is an important determinant not only of the type of irradiation facility required but also of the cost structure of that facility. As you know dose levels vary according to a number of factors including:

(i) the purpose for which the targets are being treated;
(ii) the nature of the target; and
(iii) the number of passes through the radiation field.

Holding all other variables constant, irradiation costs will vary directly with dose levels with some variation depending upon the range of tolerance provided in the minimum/maximum allowable dosage. Where tolerances are small, greater attention must be given to control and this may result in increases in the cost of control devices and control operations.

In the above calculation of source costs and source requirements an "average" dose of 4 kGy was used. The concept of "average" dose should be discussed further particularly in regard to 'service' type facilities treating a wide variety of products requiring different dose levels all with different minimum/maximum tolerance levels.

Multipass techniques smooth the dose distribution and improve the utilisation efficiency of the source material. If the package dimensions are small, the ratio of maximum to minimum dose is very nearly unity but the throughput is very small. As the package size increases in height or

depth, the maximum-to-minimum ratio also increases as does the throughput. As the package size continues to increase, the throughput eventually begins to decrease due to the decrease of the minimum dose. Therefore, there is an optimum package size, which provides the greatest utilisation efficiency, for a given maximum/minimum dose ratio, i.e. the use of a multi-pass conveyor will provide greater utilisation of the source material without sacrifice of the maximum-to-minimum dose ratio.

It is therefore desirable to administer the lowest allowable dose to the produce in order to minimize processing costs per unit of throughput. This can be assisted by carefully mating package to irradiator for best dose uniformity. This will necessitate co-operation among owners, designers and users of irradiation facilities.

With reference to our previous example, had we assumed an average dose of 1 kGy, total annual source costs would have equalled:

	$A 1 kGy	$A 4 kGy
Cobalt-60 (10 years)	180,520	731,540
Cesium-137 (10 years)	192,670	766,370
Cobalt-60 (15 years)	176,340	703,380
Cesium-137 (15 years)	179,463	713,770

In other words, source costs will vary in direct proportion to variations in dose levels.

- Transportation and installation of source material

The cost per curie of the radionuclude source material will also vary according to the distance from the supplying organisation. As Cesium-137 initially requires larger quantities of installed source material, large installation and transportation costs will be incurred. This will to some extent offset the savings on the source material acquisition. However, the necessity to replenish Cobalt-60 on a yearly or half-yearly basis would result in more plant downtime than in the case of Cesium plants which require replenishment much less frequently, e.g. every five years.

3.2 Capital costs

The main items which make-up the capital costs of a radionuclide plant include:

Building
Source frame
Source
Source pool and elevator
Ventilation and cooling
Refrigeration equipment
Working capital
Contingency
Shielding
Instrumentation
Conveyor
Control room
Dosimetry laboratory
Planning, design and engineering

Of course, for an Electron Accelerator system, machine and equipment costs and their installation costs would replace source related costs in the radionuclide facility.

Generally speaking the level of investment required will depend primarily on:

1. The scale of planned operations.
2. The type of source selected.
3. Whether the facility is designed as an independent services type operation providing irradiation services to food processors on a fee basis, or whether the facility is designed as an integrated operation within a complete food processing plant.
4. The cost of planning, design, engineering and development prior to operations.

I do not intend to cover the individual costs of planning and constructing an irradiation plant. As indicated previously, these costs are case study specific and can be obtained from engineering and plant construction agencies. Instead, I wish to discuss basic cost concepts and cost calculation methods.

o Annual cost of investment

The most desirable method of calculating the annual cost of capital invested, is the Capital Recovery With Return method. The alternative and traditional Average Investment method which separates the cost of an asset into depreciation and interest components, is considered inaccurate and not in accord with economic theory.

<u>Average investment method</u>

Depreciation is usually calculated as:

$$\text{Annual depreciation} = \frac{\text{Cost of asset} - \text{Salvage value}}{\text{Life of asset (years)}}$$

Interest is calculated as:

$$\text{Annual interest} = \frac{(\text{Cost of asset} + \text{Salvage value})}{2} \times \text{Interest rate}$$

Thus the annual cost of asset purchase under this method is:

$$\text{Annual cost of asset purchase} = \text{Annual depreciation} + \text{Annual interest}$$

Capital recovery with return method

Under this method annual cost of asset purchase is calculated as:

$$R = (C - S)\frac{r(1 + r)^n}{(1 + r)^n - 1} + S_r$$

where R = annual cost
C = cost of asset
S = salvage value
r = interest rate

The inaccuracy referred to previously tends to increase with the level of interest rates and the life of the asset, but decreases with the size of the salvage value.

The appropriate cost of an item in comparing investment alternatives is its opportunity cost, i.e. its value in its best alternative use. For variable cost items the cost of an item is given by its purchase price. For capital items, the opportunity cost is the purchase price but the

difficulty lies in apportioning this cost over a number of periods. If an items costing $C is expected to last n years with no value at the end of year n what is the opportunity cost, on an annual basis, of owning this item? One could argue that the cost could be separated into two components:

- Capital recovery
- Interest or return on investment.

These two cost elements, capital recovery and return can be expressed as indicated in the above formula.

An example

Lets suppose that an irradiation facility being evaluated is estimated to cost $2.5m. It is expected to have a nominal scrap value of $250,000 at the end of its anticipated life of 15 years. The opportunity cost of funds is 10% real (assuming zero inflation).

Average investment method

$$\text{Annual cost} = \frac{\$m(2.5 - .25)}{15} + \left(\frac{\$2.5m + \$2.5m}{2} \times .10\right)$$

$$= \frac{\$2.25}{15} + (1.375 \times .10)$$

$$= \$150{,}000 + \$137{,}500$$

$$= \$287{,}500$$

Capital recovery with return method

$$\text{Annual cost} = \$m(2.5 - .25)\,\frac{.1\,(1 + .1)^{15}}{(1 + .1)^{15} - 1} + (\$2.5m \times .1)$$

$$= \$295{,}800 + \$25{,}000$$

$$= \$320{,}800$$

The difference of $33,300 per year is a 10% understatement of the costs of ownership per year.

The extent of the inaccuracy will vary depending on the life of the asset and the interest rate (opportunity cost of funds) used. The longer the life of the project the greater the underestimation of ownership costs, and the higher the interest rate the greater the underestimation of ownership costs. The ratio of salvage value to original investment will also influence the degree of underestimation, i.e. the lower the salvage value the greater the underestimation of costs.

o Appropriate interest rate

Nominal versus Real interest rates

In the above example a real interest rate of 10% was used to calculate annual cost of asset ownership. A real rate of interest is one from which the effect of changes in the purchasing power of money, due to inflation, has been removed. Nominal interest rates express the face value of the cost or return for money at any point in time, and is not directly comparable with other rates over time if there has been a change in the value of money due to inflation.

In times of low rates of inflation the selection of the interest rate is relatively straight forward, since the nominal rate is in fact the real rate. With inflation this is not the case and the relationship between the nominal and real interest rate is as follows:

$$I_r = \frac{I_n - F}{1 + F}$$

where I_r = Real interest rate
I_n = Nominal interest rate
F = General inflation rate

As an example, the use of a 10% real rate of interest, assuming an inflation rate of 8%, is equivalent to a nominal rate of approximately 19% p.a.

It follows from the above that where real rates of interest are used, annual costs must be expressed on a constant dollar basis. Alternatively, where nominal rates of interest are used, annual costs must be expressed on an actual or nominal dollar basis.

Hence, given that the intent of calculating the cost of owning a machine in engineering economy studies is to assist in such areas as pricing decisions, enterprise selection, investment evaluation, etc, it is important that the method of calculating machine costs be consistent and correct.

- Allowance for risk

Risk in a capital budgeting context includes financial risk associated with the leverage employed by the firm, business risk associated with the type of activity the firm is

engaged in, risk of technological change, obsolescence, etc and risk due to errors in estimation of the parameters entering into the analysis. How then are these risk factors taken into account in the evaluation of an investment proposal. Often, a judicious decision is based on a number of risk accommodating criteria combined with judgement. The most simple approach is to use an interest rate or discount factor which reflects the opportunity cost of capital with a comparable risk component. In other words, a return on investment that would provide adequate incentive to invest in a project with an identical level of risk.

Firms engaged in the processing of food products, as in every case of competitive investment, are confronted with the problem of evaluating alternative applications of resources, and the relative potential returns that may be expected from each in relation to the degree of risk involved. As a result, the availability of private funds to invest in food irradiation will depend upon the anticipated final net return on investment in relation to risk involved and in comparison with alternative ventures.

Ionising energy treatment of foodstuffs is generally speaking a new and yet unproven technology and one which involves undefined problems of consumer acceptance and a high degree of obsolescence. As such, it presents a relatively high degree of risk. To attract capital, it will therefore be necessary to plan for a return on investment somewhat higher than would be required in less risky activities.

A rate of return on capital as high as 50% has been suggested by various analysts. The management of a commercial enterprise will require a rate of return, according to its judgement of the risk of the venture,

higher rates being required for propositions judged to be more risky.

3.3 Operating costs

Operating costs will depend on a number of factors including:

- Source type - radionuclide, electron accelerator etc,
- Degree of automation - manpower requirement
- Capacity utilisation - hours per annum of operation
- Scale of operation - tonnes of throughput per annum
- Utility usage - electricity, water etc.
- Source size - kilowatt of radiation output
- Maintenance schedule - labour and components
- Materials handling system
- Composition of irradiated products - changes from one operation to another.

In general, once the size of a facility is fixed, based on future expected activity levels, it is the annual operating costs which will determine the profitability of a facility. If the actual activity level differs from the designed level, movement will be within the range of operating costs for that facility. In most cases the appropriate response to uncertain or variable throughput or demand is to design a facility with excess capacity. This approach is adopted in order to minimize operating costs in the short term. In addition, facility expansion will not be required following higher than expected demand or throughput. The level of excess capacity will therefore depend on the nature of the short run or operating cost function.

3.4 Cost functions of alternative irradiation facilities

Having determined the size of a facility, based on expected future demand and throughput, it is necessary to consider the effect of variability in capacity utilisation on total and average processing costs. This variability can result from a number of causes:

1. Uncertainty in the forecast of the eventual activity level of the facility, compounded by the lead time required between the decision on facility size and the operational introduction of the facility.

2. Variable activity levels in the eventual operation of the facility resulting form both random and seasonal changes in demand.

3. Growth and other systematic changes in activity levels over the operational life of the facility. This is a problem, of course, only to the extent that the facility cannot be systematically expanded or contracted over its life span in response to these changes. I understand that some expansion of source size is possible provided that it was allowed for during the design and construction phases of the project.

A comparison of the cost functions of the two alternative sources as illustrated in Diagram 2 may help to identify some of the implications of this variability in throughput levels.

Diagram 2

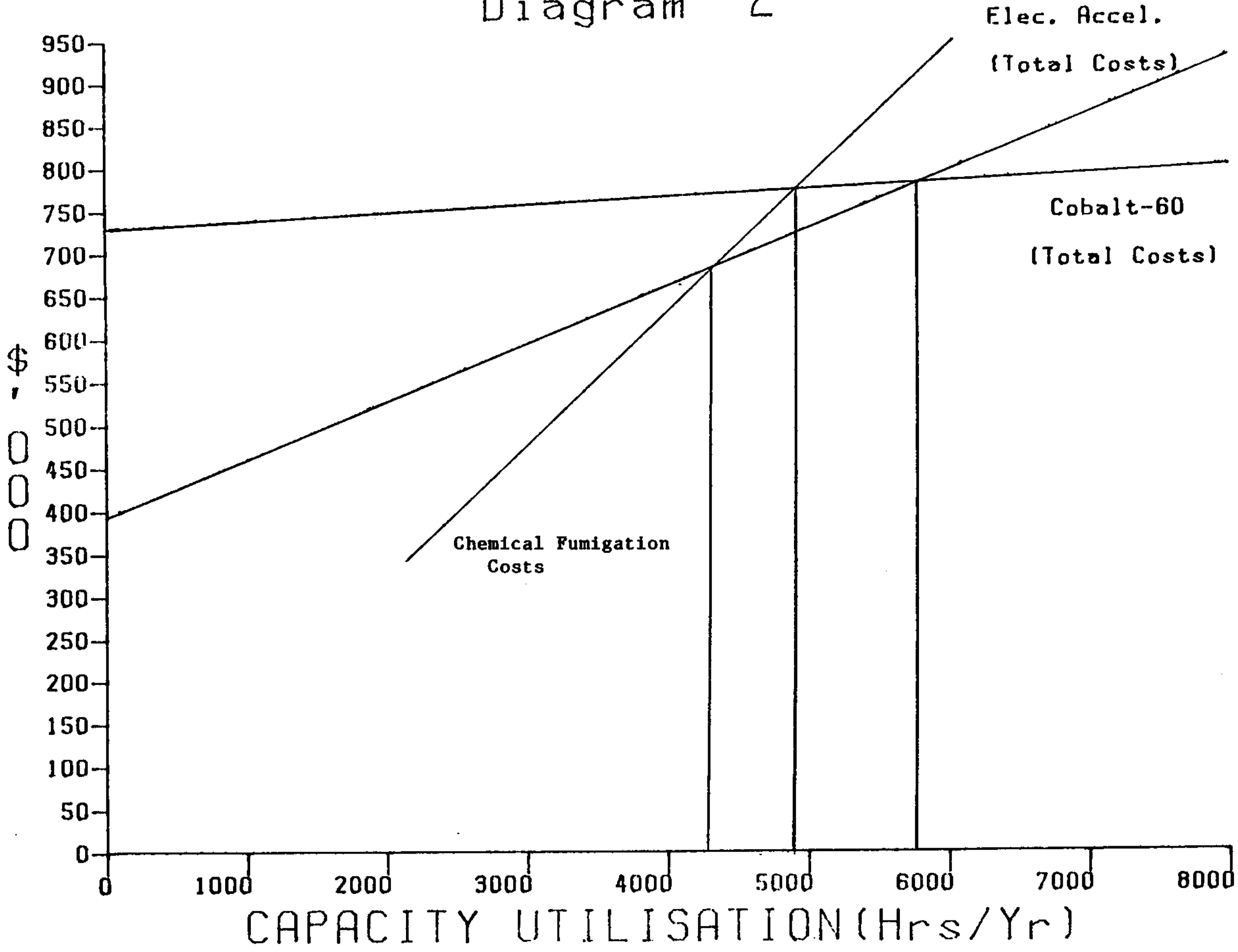

Elec. Accel.
(Total Costs)
Cobalt-60
(Total Costs)
Chemical Fumigation
Costs
$ '000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
1000
2000
3000
4000
5000
6000
7000
8000
CAPACITY UTILISATION(Hrs/Yr)

Diagram 2 is based on cost relationships formulated by Brynjolfson back in the early seventies and therefore may not be indicative of the actual level of current costs. However, the form of Brynjolfson's cost relationships, I feel, may still be indicative of current relationships.

As illustrated by Diagram 2 total fixed costs account for a greater proportion of total costs for the radionuclide facility compared with the electron accelerator facility. The investment required in source material, i.e. Cobalt-60 is the main cause of this difference in fixed costs. A comparison of operating costs shows that the rate of increase in costs resulting from increased levels of throughput is greater for the electron accelerator facility. The use of the radionuclide source material is independent of the level of throughput whereas the extent of power usage in the electron accelerator facility is almost totally dependent on throughput levels.

Diagram 2 indicates that at full capacity (8000 h/yr) a 5MeV electron accelerator facility with a beam power rating of 22 kW is more costly per kilogram of throughput than a 1.5M curie Cobalt-60 facility both processing 8 tonnes per hour for 8000 hours.

However, if the level of capacity utilisation falls it could be expected that the electron accelerator would eventually achieve a cost advantage per unit of throughput over the radionuclide facility. In the situation illustrated in Diagram 2 the electron accelerator has a cost advantage over the Cobalt-60 facility for capacity utilization levels up to 5800 hours/annum (or 46400 tonnes/annum). Past that point the Cobalt-60 facility has a cost advantage.

One implication of the above analysis is that for a facility treating a wide variety of products with different doses and with varying throughput levels, e.g. agricultural products, a low capacity utilisation factor will result. Hence it may well be that, in such circumstances, electrically driven irradiation sources may be preferable to radionuclide source facilities on commercial grounds.

4. OTHER COST CONSIDERATIONS

4.1 Techno-economic considerations

Any commercial evaluation of the profitability of an irradiation facility for the treatment of agricultural products must address a number of techno-economic aspects which will impact on processing costs. These aspects include:

1. The quantity of product to be treated and the unit value of that product, i.e. a high unit value product can be treated at small volumes of throughput, whereas a low unit value product will require high volumes.

2. The plant must be located at a convenient point in the flow of product from harvest through processing to distribution in the market place. Transportation costs and potential delays are a vital part of all determinations of costs.

3. Product packaging, size of container, palletising system, and the package density are of vital importance in the designing of a multi-product oriented plant.

4. Logistical and environmental conditions in food production and distribution require a short residence or hold-up time in the irradiation facilty.

5. The relative commercial feasibility and cost effectiveness of 'multi-product' and 'service' facilities in an agricultural product environment.

6. The transportation, handling, scheduling, public acceptance and related questions must be considered in any realistic assessment of the feasibility of irradiation of fresh products since most must be marketed without delay.

These techno-economic considerations translate into the following technical requirements for a 'service' type facility:

- The requirement for great flexibility in the dose to be applied;
- high speed of the product conveyor system;
- small product hold-up volumes and short product hold-up times in the irradiation process;
- product conveyor system should not represent a cause of potential physical damage to the food products;
- ability to handle sharp fluctuations in through-put resulting from the high degree of seasonality in the production of most agricultural products;
- the capability to upgrade the facility as increased throughput, user and consumer acceptance and economic viability are achieved;

- the need to construct refrigerated storage facilities to hold product prior to and following irradiation in order to prevent re-infestation and/or quality degradation. The capacity of this storage will be determined by the processing capacity of the plant, the degree of seasonality (peak supply throughput) of the products treated, and the logistics (packaging, distribution and transportation etc) of the marketing process.

It is therefore desirable to maximize the product handling aspect subject to capacity constraints and to minimize the product hold-up and storage time at the irradiation facility. Because of the necessity to accept the product in its routinely and traditionally applied packaging or transportation form, the irradiation plant may have to sacrifice on source efficiency. In other words the accommodation of the food product as it is presented to the irradiator (in order to reduce handling and hold-up times) will mean that the utilization of the irradiation source will fall below that technically possible.

4.2 Economic aspects of a 'service type' facility

The seasonal nature of most agricultural industries will ensure that a treatment plant, designed to handle a constant throughput, will either experience periods of excess capacity or will be unable to process the quantities of product demanding treatment. The former will result if capacity considerations are based on peak intake volumes, while the latter will result if a constant minimum base load is used to determine the capacity of the plant.

Excess plant capacity will result in low source utilisation, where a radionuclide source is used, since the

source is continuously emitting energy whether or not the plant is in operation. This factor is of course not applicable in the case of electron accelerator systems where the power can be turned off when not in use. Plant and equipment, excluding source material, will also be under-utilized and increased capital costs per unit of output will result. Variable costs by definition will not be effected by underutilization of the source or the plant and equipment. An indication of the additional costs incurred as a result of a reduction in capacity utilization can be obtained by reference to Diagram 2.

Insufficient capacity to process the quantity of product requiring treatment would of course result in either the loss of product because of lengthy storage and hold-up times and/or increased costs as additional storage facilities would be required to handle the surplus product.

In either situation average cost per unit of output will be greater than for a plant treating a constant level of throughput for which adequate capacity exists. In each of the situations, the capacity utilization factor is the most important determinant of costs.

What ever the capacity of a plant or its scheduled utilization, output is also affected by loss of throughput during emergency shutdowns, or periods of transfer form one type of processing to another.

This situation can be expected to apply with respect to the treatment of mangoes in Queensland. The relatively short season (approximately 10-12 weeks) of mangoes would require that a treatment plant would need sufficient storage facilities to allow subsequent treatment when capacity became available. As short storage times for mangoes are

essential any base load throughput which did not require storage could be temporarily suspended to provide this capacity. There may well be constraints on the degree to which this base load can be suspended and this should be considered in the determination of plant capacity.

4.3 Integration or specialization

In the case of an irradiation facility fully integrated into a total food processing operation the investment and costs would be absorbed by the food processor rather than a negotiated throughput cost as in the case of an independent food irradiation service. Obviously, efficiency will be higher and costs lower to the extent that specialization permits simplification of source geometry and conveyor design, increased efficiency of source utilization and greater plant utilisation. However, specialization will only be possible where plant size can be matched to expected throughput.

In the early stages of development of irradiation treatment it is likely that facilities will be designed and constructed to operate with diversification as to both processes and products until sufficient market demand develops to make possible the efficiencies of process or product specialization at high volumes.

4.4 Some recent cost estimates

The cost estimates in Table 2 were obtained from a private company currently evaluating IET facilities. All costs are in 1984 US dollars.

Table 2. Total annual costs - electron accelerator

	Annual operating schedule 2000 h/yr	 6000 h/yr	 8000 h/yr
Source - 15 MeV 50 kW	$US	$US	$US
Annual capital cost ($3.7m @ 10% over 15 yrs)	485,000	485,000	485,000
Annual operating costs	400 000	800 000	1,000 000
Utility costs	120 000	360 000	480 000
	1,005,000	1,645,000	1,965,000
Hourly cost	500	275	245

Throughput and cost per tonne

Dose (kGys)	Throughput/hour (t) electron	 x-ray	Cost per kilogram treated ($US) 2000 hours electron	 x-ray	 8000 hours electron	 x-ray
.1	1 630	325	.30	1.54	.15	.75
.3	545	108	.92	4.63	.45	2.27
1	163	33	3.07	15.15	1.50	7.42
2	82	16	6.10	31.25	2.99	15.31
4	41	8	12.20	62.50	5.98	30.63
5	33	6.6	15.15	75.76	7.42	37.12
7	24	4.6	20.83	108.70	10.21	53.26
30	5.5	1.1	90.91	454.55	44.55	222.73

It must be kept in mind that these cost figures were provided by a machine supplier and as such may be somewhat biased, on the low side of course. Unfortunately, there is no electron accelerator currently in operation to substantiate or dispute these cost estimates. The initial costs for commercialising this technology are uncertain. The construction of a test accelerator which is specifically engineered for mass production to process food, would provide a much better understanding of eventual costs as well as providing a dedicated machine for efficacy studies with bremsstrahlung radiation.

5. SUMMARY AND CONCLUSIONS

1. There are a large number of variables involved in the assessment of the relative economic feasibility of alternative food irradiation treatment facilities. These variables can be summarised under three headings:

   (i) variables concerned with the physical characteristics of products to be treated;

   (ii) variables concerned with the operational characteristics of the plant to be used;

   (iii) variables concerned with costs of establishment and operation of an IET plant.

2. With respect to radionuclide sources, Cobalt-60 currently has a cost advantage over Cesium-137 due mainly to the greater source efficiency factor obtainable with Cobalt and the higher levels of radiation energy emitted by that radioisotope. Having regard to this cost advantage, and also to a number of

other practical and technical considerations, particularly the superior target penetration achieved by Cobalt-60, Cobalt has been preferred as a radioisotope source material.

3. Although it has been found that for processing plants running a near full capacity, Cobalt has a marginal cost advantage over electron accelerator systems, a number of other aspects should be considered including:

   (i) the higher level of source utilisation efficiency obtainable with electron accelerator systems;

   (ii) the greater versatility of electron accelerator systems.

4. The greater versatility of electron accelerator systems and the lower unit operating costs compared with radionuclide systems at lower levels of capacity utilisation suggest that an electrically driven irradiation facility would be preferable for plants in which a wide variety of products are to be treated, at varying dose rates, and where throughput levels are not known with certainty due to the seasonal nature of throughput.

5. Finally, I would like to reiterate a point which I made earlier regarding the relationship between costs, plant design and application. As I indicated then, the evaluation of the commercial feasibility of an irradiation facility is specific to the characteristics of that facility. Thus, in regard to the relationship between costs and facility design I stress that the best design approach for a specific application must be

worked out on its own merits to achieve the least cost result. This means that the design agency and the facility owners must get together early in the game to work out a commercially feasible solution for the application involved.

THANK YOU

LECTURE 25

MARKETING STRATEGIES - CONSUMERS

C. CAMPBELL

AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

MARKETING STRATEGIES - CONSUMERS

AUTHOR: Cathy Campbell
1985

MARKETING STRATEGIES - CONSUMERS

The irradiation of food will be a hot issue this decade. Already a number of countries have announced the widespread use of radiation to preserve foods and scientists in Australia are also investigating its use for certain products.

The irradiation of foods has worldwide implications. It is viewed by economic experts as a means of increasing food supplies. It could also mean expanding exports of agricultural products. The process could help save some of the estimated 25-30% of the world's food supply that is lost each year because of pests and spoilage.

As Australia's largest consumer organisation, the Australian Consumers' Association (ACA) has a vital role in providing information, so consumers can make an informed choice, as well as participating in formulation of standards to increase the quality of products, including foods. Most people know us by our monthly magazine, CHOICE, where we report on tests of consumers products. (Maybe in the near future we could be testing foodstuffs subjected to irradiation.)

ACA's basic ethic rests on the 4 primary rights of the consumer

- the right to be informed
- the right to be heard
- the right to safety
- the right to choose.

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With these rights in mind, we have already published two articles this year on food irradiation in CHOICE, covering the irradiation process, history, current status, application and safety. Consumers want information in all these areas especially the safety aspects.

The use of radiation always arouses some fears amongst consumers. However, the US Food & Drug Administration (FDA) has stressed that treatment of food at the levels of radiation proposed would add no radioactivity to the foods, nor would it expose consumers to any radioactivity. 'Food that is not made radioactive cannot expose consumers to radiation', the agency emphasised, adding that the type of radiation to be allowed 'will not induce in foods any radioactivity that can be detected, even by methods that detect the presence of radioactive isotopes that occur naturally in all foods.'

Although irradiation does not make food radioactive, it can produce chemical changes in it. A special committee formed by FDA's Bureau of Foods reviewed the world's scientific literature on the effects of irradiation and concluded that any changes that would occur in food are inconsequential compared to changes that occur normally in storage or in cooking. FDA scientists also note that in all studies in which irradiated foods were fed to animals over many generations, no adverse effects were found that could be attributed to the irradiation, a point also made by international and regulatory groups in other countries.

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Currently, many foods are treated with chemical additives, pesticides, or some other substance to protect them from insect and microbial contaminants and to give them extended shelf life. Irradiation presents another prospect for maintaining the quality of foods. It might be used, for example, as a replacement for the controversial fumigant ethylene dibromide (EDB), to control insects in certain agricultural products. EDB is a known animal carcinogen.

A key part of FDA's proposal states that food treated with ionising radiation 'shall receive the minimal radiation dose reasonably required to accomplish its intended technical effect and not more than the maximum dose specified by the applicable regulation.' Thus, despite a 100-kilorad ceiling, FDA would expect industry to use only as much radiation as would be needed.

Under the proposal, FDA also would monitor industry compliance with requirements. Food producers would be required to maintain records of radiation doses used for up to one year past the expected shelf life of a product, with all records subject to examination by FDA inspectors.

Besides complying with FDA's irradiation regulation, food processors would haveto adhere to federal plant and worker safety requirements of the Nuclear Regulatory Commission and the Occupational Safety and Health Administration.

Will we have similar controls and safety measures in Australia? Will industry only use the minimum dose to

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have the desired effect and not the maximum dose? Will it be possible for a batch of food to be inadvertently irradiated several times along the processing chain?

The National Health and Medical Research Council (NH&MRC) is currently drafting regulations to control irradiation of food in Australia. Since 1979, the NH&MRC has acted to protect consumers by denying entry into Australia of any irradiated food without NH&MRC approval. The council also recommended that no food be irradiated in Australia without specific approval. Since then the NH&MRC has been considering the safety of food irradiation processes.

In 1980 Australia joined the International Food Irradiation Project (IFIP) which was founded in 1970. Funded by many nations, IFIP collected all available data on the toxicological safety and wholesomeness of irradiated food. IFIP also arranged for independent feeding trials and tests to be carried out.

As IFIP accumulated information it was presented to the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food. By 1976 this committee concluded that it was perfectly safe to eat irradiated potatoes, wheat and flour, strawberries, pawpaws and chicken. On the basis of these findings the Codex Alimentarius Commission prepared a Recommended International General Standard for Irradiated Food approving the treatment for these five foods. A Recommended Code of Practice for the Operation of Radiation Facilities used for the Treatment of Foods was also prepared.

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By late 1980 the wholesomeness of irradiated onions, rice, fish, mangoes, dates, cocoa beans, pulses, spices and condiments had been accepted. By then the Joint Expert Committee also concluded it was acceptable to irradiate any food to an average dose of 10 kilogray.

Both the Standard and Code of Practice were revised.

The Food, Science and Technology Subcommittee of the NH&MRC has adopted the Codex Alimentarius International General Standard and the Code of Practice in principle. At the moment they are being transformed into a format suitable for adoption by the NH&MRC and should be presented to the council by June this year. Once this happens it will be up to each State to legislate to include standards for irradiation in their food laws as the administration of food Acts is the responsibility of each State or Territory. ACA hopes these standards will be uniform for all States.

It is a long and continuing battle to have Australian foods labelled so that consumers know what they are eating. However a spokesperson for the NH&MRC has told ACA that the council is committed to ensuring that irradiated food will be clearly labelled as such. The council believes this is necessary both because consumers have a right to know and because the label will tell consumers that some foods, especially fruits like pawpaws and strawberries, will have a longer storage life. We believe the label

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should read "treated with radiation" rather than one of the more confusing alternatives such as "treated with ionizing energy".

Consumers are also interested in the byproducts of the nuclear industry which in the past has not been keen to inform the public about details of hazardous waste disposal.

The consumer movement is 'marketing' the process of irradiation and will continue to give consumers information that allows them to make an informed choice.

Cathy Campbell

Currently Dietitian-Nutritionist and Supervisor of Food and Chemicals Testing for the Australian Consumers' Association for over 2 years.

Gained a Bachelor of Food Science and Nutrition from the W.A. Institute of Technology and a Diploma in Nutrition and Dietetics from the Flinders University of S.A.

Past experience as a Dietitian-Nutritionist with the Queensland Health Department's Aboriginal Health Program, Royal Perth Hospital and Prince Henry Hospital in Sydney.

Worked in a number of professional bodies and committees over the last seven years.

LECTURE 26

MARKETING STRATEGIES - SUPERMARKETS

R. CLAIRS

AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

WORKSHOP ON COMMERCIALISATION OF IONISING ENERGY TREATMENS OF FOOD

8th MAY 1985

AUSTRALIAN ATOMIC ENERGY COMMISSION

MARKETING STRATEGIES

SUPERMARKETS

R. Clairs

ROLE OF SUPERMARKETS IN THE AUSTRALIAN FOOD DISTRIBUTION CHAIN

To commence, I will identify the role of the Supermarket in our Australian Society. It is the focal point for the purchasing of the majority of the family food requirements.

The evolution of the Supermarket over the past 3 decades is a result of the social, cultural and economic environment, combined with the demographic profiles, consumer demands and the introduction of trends and technologies from other cultures and other countries.

It is indeed a building, housing a range of merchandise, satisfying most of the weekly requirements and the wants and needs of the Australian consumer.

Within the Industry, there are many types of Supermarkets, ranging from sophisticated Hi-Tech stores with electronic scanning registers and service departments, to very basic, cheap food outlets who rely on price alone to attract their customers.

The result of this wide range of outlets, means that there are varying degrees of interest in modern technology and indeed in the ranges of merchandise that are available for them to be sold.

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RESPONSIBILITY OF SUPERMARKETS

The next point I would like to cover is the responsibility of the Supermarkets as we see it.

Supermarkets do have a responsibility to ensure that all food sold - that is fresh and processed - conforms to the Pure Food Acts, the Weights & Measures regulations and the local Public Health requirements.

There is a great degree of emphasis in the Supermarkets and indeed all retail outlets in Australia to maintain a high degree of hygiene, and to ensure that all Food sold is of a standard acceptable to these regulations and consumers.

To that end, all Buyers that operate in the majority of Supermarkets have been educated to recognise and accept the highest degrees of standards only.

TRENDS IN SUPERMARKETS

Let us now deal with trends that have occurred during the past decade in the Supermarket Industry.

There has been an increase in consumer awareness for their diet. There has been an enormous increase in the knowledge of consumers in the selection of the food that they purchase.

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Consumers over these past years have insisted on having a greater knowledge of the ingredients contained in any food they purchase, therefore, we have seen the introduction of Ingredient Labelling on many products.

Simultaneously, we have seen a great number of consumers changing their dietary habits to eat merchandise that has lower Sodium content, a higher Fibre content or indeed there has been a greater degree of fresh rather than processed food sold.

We have seen the growth and emergence of the Health Foods or Nutrition Centres which specifically cater to this extremely diet conscious consumer that is emerging today.

The ranges of fresh Produce that have been sold throughout Supermarkets and Food Distribution chains has increased dramatically as this demand has pushed it forward.

New exotic fruits have been introduced into the Australian Market that were not known five years ago. Fresh Fish has become an extremely popular commodity group to replace somewhat the high demand of consumption that red meat enjoyed in the Australian diet.

Ranges of nuts, legumes and natural grains have increased dramatically over these past few years to once again satisfy that demand.

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SOURCING

The buyers in Supermarket chains of today must be skilled in identifying sources of supply and to ensure that supply is maintained at a rate consistent with that demand, so that the customers coming into the Supermarkets are able to purchase their requirements when they want them.

The system for sourcing and distributing merchandise throughout this country is quite unique when one considers the enormous distance between towns and capital cities and the minimum delay in ensuring that fresh stock is available on those premises when required.

The buyers are skilled in analysing the requirements of customers in terms of this high recognition for Ingredient Labelling and for freshness.

MARKETING

With the introduction of any new technology into this extremely competitive and very dense field, it is absolutely necessary that in the first instance a market for such an introduction is clearly established.

Before the commercialisation of this process is undertaken on a large scale in this country, research would need to be undertaken to specifically identify which markets are going to be most attracted to the ranges of products that can be treated in this manner.

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Research into the demographic, psychographic and sociographic profiles of the Australian consumers will be able to determine where to position products to ensure maximum return on investment.

Having established that market, it is then necessary to clearly identify which products and in which manner should the products be finally presented to those customers. There is absolutely no point in advancing with this sophisticated technology and creating a magnificent product that goes no further than the laboratory test bench.

The next step in this process is to establish the demand for such products so that estimates of production can then be ascertained to ensure that the tooling up of machinery and the investment of capital is able to provide a satisfactory return on investment also.

This can be done in a variety of methods, but the most proven of course is direct individual market surveys.

The next step in this process is to establish then which distribution channel should be used to get those products to their final destiny - i.e. the customer.

Several alternative distribution channels are available and once again, market research is the best method in which to finally determine which channel should be chosen.

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There is no reason why more than one channel should not be selected.

Next step in the marketing process is to create an awareness campaign. Depending upon the distribution channel whether that be through Supermarkets, Pharmacy stores, Wholesalers or direct selling. An awareness campaign through that channel needs to be created to bring to the attention of the prospective consumer that the product or the process is available.

As part of that awareness campaign, there is a very positive need to clearly identify the benefit or the perceived benefit to the end user.

If a customer has a choice of purchasing at a similar price a product that she has used, known and trusted for a number of years and another product just introduced with no perceived benefit, then she will remain true to the well established product. Therefore, it is necessary that if this high technology that we are talking of today does provide a distinct long term benefit to the consumer, then that should be the strongest feature of any marketing campaign. This may infact effectively place a premium price on the product but the consumer today is prepared in many cases to pay a premium if indeed there is a positive benefit attached.

So, therefore, throughout this very brief address, I have endeavoured to outline to you the role of the Supermarket responsibilities some trends in the Industry, methods of sourcing and to give some very brief overview of a marketing plan that would need to be introduced.

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I thank you for the oppotunity of addressing you today and I would now welcome any questions.

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LECTURE 27

THE CODEX STANDARD & CODE OF IRRADIATED FOODS

L. ERWIN

AUSTRALIAN SCHOOL OF NUCLEAR TECHNOLOGY

WORKSHOP ON THE COMMERCIALIZATION OF IONISING ENERGY TREATMENT OF FOOD, 29 APRIL - 10 MAY 1985

THE CODEX STANDARD AND CODE FOR IRRADIATED FOODS

Laurie Erwin, Codex Contact Point for Australia
Export Inspection Service
Department of Primary Industry, Canberra

At its 15th Session in July 1983 the Joint FAO/WHO Codex Alimentarius Commission adopted a Codex General Standard for Irradiated Foods and a Recommended International Code of Practice for the Operation of Radiation Facilities Used for the Treatment of Foods (Attachment 1).

The Codex Alimentarius Commission

2. In order to appreciate the significance of the Codex work on irradiated foods, it is necessary to provide a brief background on the programme.

3. The Codex Alimentarius Commission is the governing body of the Joint FAO/WHO Food Standards Programme. It was established in 1962 with the objectives of coordinating and rationalizing international activities in food standardization. Its main functions are:

- to facilitate international trade through the removal of those non-tariff barriers caused by differing national food standards;
- to protect the health of consumers and ensure fair practices in the food trade; and
- to promote coordination of all food standards work undertaken by international governmental and non-governmental organizations.

4. The Commission prepares international food standards for products of importance in world trade and recommends them to the 125 member governments for adoption in place of their national standards. Documents of an advisory nature, such as codes of hygienic and technological practice, are also developed.

5. Codex standards are already succeeding in reducing the complexity and expense of catering to widely different import requirements and creating a greater degree of consensus between trading countries.

6. The Commission is also achieving success in coordinating and rationalizing the work of international organizations involved in food standardization such as FAO, WHO, OECD, ECE and ISO. This is essential to remove non-tariff barriers.

7. Under the Codex Acceptance Procedure, governments are urged to adopt Codex standards into their domestic food law. Acceptance involves an undertaking to allow the free distribution of products complying with the standard.

8. One of the purposes of Codex standards is to remove discrimination, on public health and quality grounds, against imported foods. They do not cover quarantine and tariff aspects.

9. Acceptance of Codex standards does not directly affect export requirements. However, acceptance by other countries does influence the processing of foods for export which will have to comply with the requirements of the importing country. Notwithstanding this, a country's export standards need to allow scope for processors to pack for other markets or to compete with other exporters.

10. To date, the Commission has finalised and sent to governments for acceptance 200 international food standards and over 30 associated codes of practice. Maximum pesticide residue limits for over 1,300 pesticide/commodity combinations and a number of methods of analysis and sampling have also been distributed.

Codex Involvement with Irradiated Foods

11. Before widespread use of food irradiation could be introduced, the 'wholesomeness' of the treated foods had to be ascertained. This was assessed in terms of whether the process produced any nutritional changes; achieved the desired microbiological criteria without the development of radiation resistant or genetically altered microoroganisms; and produced no toxicologically significant radiolytic products.

12. A Joint FAO/IAEA/WHO Expert Committee (JECFI) was first convened in 1964 to consider the wholesomeness of irradiated foods. Taking as a premise that the irradiation of food resulted in the production of radiolytic products in the food, the Expert Committee adopted the view that these products represented additions to the food. It therefore concluded that the assessment of the wholesomeness of irradiated foods should follow procedures similar to those generally used for evaluating the safety of food additives and should be pursued on a food-by-food basis.

13. The 6th Session (1968) of the Codex Alimentarius Commission decided that standards and codes for the irradiation treatment of foods should be elaborated by the Codex Committee on Food Additives which is hosted by the Government of the Netherlands and meets in The Hague.

14. A subsequent meeting of JECFI (1969) had available for consideration the results of a number of toxicological studies carried out on irradiated wheat, potatoes and onions. It reviewed the comparative data on several varieties within a crop, and accepted extrapolation of data from a major variety to all varieties of that crop. The Committee recommended temporary acceptance of irradiated wheat and potatoes as wholesome, and requested further studies on onions.

15. Much of the later data on irradiated foods has been generated by the International Food Irradiation Project (IFIP). This project, initiated in 1970, was supported by 24 countries (including Australia) and was centred on Karlsruhe in the Federal Republic of Germany.

16. The results of the IFIP program were documented in 66 Technical Reports, 4 Activity Reports, two books (ELIAS and COHEN 1977, 1983) and a number of publications in scientific journals.

17. In 1976 a meeting of JEFCI recommended the unconditional acceptance of irradiated wheat, potatoes, chicken, papaya and strawberries, and provisional acceptance of irradiated cod and redfish.

18. On the basis of this work by JECFI the Codex draft Standard for Irradiated Foods and the associated Code of Practice were prepared. These were adopted by the 12th Session (1978) of the Codex Committee on Food Additives and endorsed by the 13th Session (1979) of the Commission as a Recommended International Standard and Code of Practice respectively.

19. In 1980 a further JECFI meeting concluded that any foods irradiated up to an overall average dose of 10 kGy

posed no nutritional, microbiological or toxicological hazard. Technically, it was considered that x-rays were suitable as a source of ionising radiation and that food irradiation was a physical process similar to the conventional processing techniques of heating, freezing or microwaving, and as such could not be regarded as 'adding' anything to the food.

20. The 14th Session (1981) of the Commission agreed that the General Standard and Code be amended in line with the conclusions of JECFI and that the following be taken into account:

(i) x-rays at an energy level of 5 MeV were suitable as a radiation source;
(ii) re-irradiation, under certain conditions, could be considered as good irradiation practice;
(iii) any food irradiated at an overall average dose of up to 10 kGy posed no nutritional, microbiological or toxicological threat to public health;
(iv) there was no scientific basis for the declaration on the label that a food had been irradiated.

21. The 15th Session (1983) of the Commission adopted the revised Standard and Code (Attachment 1).

22. However, while the revision in relation to (i) and (ii) above proceeded smoothly, there was considerable controversy surrounding both the microbiological and labelling aspects.

23. The 16th Session (1979) of the Codex Committee on Food Hygiene had expressed concern that sub-lethal, low dose irradiation may cause problems including increased radiation resistance, increased pathogenicity associated

with genetic changes of surviving micro-organisms, and selective destruction of vegetable cells preventing competitive growth of microorganisms prior to outgrowth of Clostridium botulinum spores.

24. At the 12th Session (1982) of the Codex Committee on Processed Meat and Poultry Products, concern was again expressed that irradiation at sub-lethal doses could result in radical changes in the bacterial flora.

25. Consequently, FAO, WHO, IAEA and the International Union of Microbiological Societies convened a meeting (December 1982) on "The Microbiological Safety of Irradiated Food". This meeting concluded that "irradiation induced genetic mutation of pathogens in food did not create an increased hazard to health and - there would be no qualitative difference between the kind of mutation induced by ionizing irradiation and that induced in any other pasteurization/partial preservation methods such as heat treatment or vacuum drying" (refer Attachment 2).

26. The responsibility for determining the method of labelling of irradiated foods has been under consideration by the Codex Committee on Food Labelling for a number of years.

27. The revised Codex General Standard for Irradiated Foods still contains no specific labelling provisions. It simply requires the labelling to be in accordance with the relevant provisions of the Codex General Standard for the Labelling of Prepackaged Foods which is only now being finalized.

28. The problem of labelling or irradiated foods is far from simple. Many irradiated raw or processed foods can

later be processed into different products. Furthermore, irradiated foods, whether processed or raw, can be used as ingredients in manufactured foods. These foods may be prepackaged or shipped in bulk and may be directed either to the consumer or to the food industry for further processing or packaging.

29. The form of label information is also a complex problem: should the label state only the fact of irradiation or give, as well, the technological purpose of the irradiation process? How should this type of information be stated on the label ? What prominence should it be given in relation to the name of the food ?

30. It could be argued that a potato irradiated to inhibit sprouting is no different from a potato treated with chemicals or from an untreated potato stored under certain conditions of temperature and humidity to extend shelf-life. In terms of health protection, it would not seem necessary to identify such products as having been irradiated. In fact, the declaration of residues or contaminants in food (eg. residues of substances used in agriculture and animal husbandry, processing aids or heavy metal contaminants) is usually not required under national regulations and is not required under the labelling standards established by the Codex Alimentarius Commission.

Developments Within the Codex Committee on Food Labelling

31. The 17th Session (October 1983) of the Labelling Committee was unable to take a decision on labelling because the delegations of Canada, Denmark, FR Germany, Sweden, United Kingdom and United States of America advised that they could not indicate a final position since national reviews were still in progress.

32. The Committee tentatively decided that "a food which has been treated with ionizing radiation/energy shall include on the label the statement 'treated by ionizing energy'". However, Denmark, France, FR Germany and Sweden reserved their position on the basis that they preferred declaration of 'treated by ionizing radiation'. No decision was taken on how second generation products should be labelled.

33. At the recent 18th Session (March 1985) of the Committee the labelling or irradiated foods remained highly controversial.

34. The observer of IAEA expressed the view that

- "labelling declarations should not be mandatory and that the requirements to label irradiated foods should be left to national authorities
- labelling provisions related to irradiated ingredients would be of little value."

35. The delegations of Denmark, Thailand, Colombia, India, Spain, Trinidad, UK and FR Germany considered that the phrase "treated with ionizing energy" could mislead the consumer and preferred use of the term "irradiation".

36. However, the observer of the International Organization of Consumer Unions (IOCU) opposed the term "irradiation" because a survey had shown that the term held extremely negative connotations for consumers with regard to health and radioactivity. To encourage positive thinking IOCU had suggested use of an internationally recognized symbol in conjunction with an education program.

37. Finally, on the proposal of USA and UK, the following

wording was adopted for inclusion in the General Labelling Standard:

> 5.2 Irradiated Foods 1/
>
> 5.2.1 A food which has been treated with ionizing radiation energy shall indicate on the label that treatment in close proximity to the name of the food.
>
> 5.2.2 When an irradiated product is used as an ingredient in another food, this shall be so declared in the list of ingredients.
>
> 5.2.3 When a single ingredient product is prepared from a raw material which has been irradiated, the label of the product shall contain a statement indicating the treatment.
>
> 1/ The text of this section remains under review.

38. Australia expressed concern that the above wording would leave it open for national authorities to require many different labelling requirements. Such diversification created the risk of non-tariff barriers. The Committee noted an Australian proposal to urge national authorities to adopt the provision without including more stringent provisions in the form of specific mandatory wording. This would enable manufacturers to use different forms of wording provided that it adequately informed the consumer of the process and was not deceptive or misleading.

39. It is interesting that a recent consumer survey in Canada gave preference to label declarations such as "freshness extended by irradiation" and "ionized fresh". It is understood that the US industry now favours such declaration of the benefit along with the treatment.

40. In summary, the present situation in Codex was summed up by the Secretariat at the Labelling meeting when it expressed regret that it had not been possible for the Committee to provide more precise advice. It pointed out that the old Codex General Labelling Standard finalized in 1969 had included the following provision:
"Foods which have been treated with ionizing radiation shall be so designated".

41. A copy of the relevant section of the Report of the Labelling Committee is included as Attachment 3.

Situation in Australia

42. Within Australia, the States and the Territories are responsible for the administration of domestic food law. However, a high degree of uniformity is achieved through the activities of the Food Standards Committee of the National Health and Medical Research Council. This prepares Model Food Standards which are recommended to the States and Territories for uniform adoption.

43. An Australian Model Food Standard for Irradiated Foods, based on the Codex Standard, is in the final stages of development. Because Codex has not been able to provide specific labelling requirements, consideration is being given to the alternatives "treated with ionising energy" or "treated with ionizing radiation".

44. As far as exports of Australian food products are concerned, Ministerial Orders under the Export Control Act (1982), administered by the Department of Primary Industry, impose a variety of requirements and conditions before export approval is granted. The purpose is to ensure that Australian products entering overseas markets are of a high and consistent quality and are correctly

described. These export controls are part of a broader range of Government measures designed to maintain and improve Australia's access to overseas markets.

45. Although the Ministerial Orders do not contain specific provisions on irradiation, they would allow approval of such treatment where it is approved by the importing authorities. The Department would, of course, ensure that the labelling requirements of the importing country are complied with.

Conclusion

46. In an address to an Australian Symposium in October 1983 Professor J F Diehl (Karlsruhe) stated that "psychological barriers to a process associated with the word 'radiation' are still formidable; it appears however, that acceptance by authorities, food industry and consumers continues to grow". I wonder whether there has been much progress in the eighteen months since these words were spoken. Certainly the treatment remains controversial.

LECTURE 28

FACILITY DESIGN, INSTALLATION & OPERATION

A. FLEISCHMANN

IAEA/RCA ASIAN REGIONAL PROJECT
WORKSHOP: FOOD IRRADIATION
FACILITY DESIGN, INSTALLATION & OPERATION

A.W. Fleischmann
Officer in Charge, Radiation Health Services
Department of Health, N.S.W.
Joseph Street, LIDCOMBE, N.S.W. AUSTRALIA. 2141

The purpose of this lecture is to look at some problems that may arise when considering the designs, construction and use of a facility that could contain up to tens of petabecquerel (serveral million curies) of either cobalt-60 or caesuim-137. In essence the discussion can be broken into two quite independent areas of preoperational - which covers design, construction and the loading of the sources all of which is carried out by contractors - and the operational stage which is carried out by staff.

The general philosophy of radiation control now requires that radiation exposures be kept as low as is reasonably achievable and each of the steps identified (design, construction, loading and operation) can contribute towards this objective. It is the purpose of this paper to briefly cover the way in which this can be done.

Before embarking on details it should be mentioned that in Australia the control over the safe use of ionizing radiation is a state responsibility so that each state has its own Radioactive Substances Act or equivalent. Under that Act regulations are drafted which lay down permitted exposure levels for radiation workers and for members of the public. Other parts of the regulations deal with powers relating to licensing and the minimizing of radiation exposure levels. Essentially, we endeavour to enforce the requirements of the International Commission on Radiological Protection.

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To keep radiation exposures as low as possible a number of "worst case" assumptions can be made when considering the design of such a plant. These include that:

1. the radioactive source is the maximum activity the facility can accomodate. This may, in fact, not be the case for some considerable time if ever;

2. the permitted exposure levels for all personnel are the same as those for members of the public;

3. the plant would be operating - that is, the source would be in the exposed position - for times well in excess of what would normally be the case.

These three assumptions as well as a number of lesser ones help to assure that radiation exposures are well within the accepted limits.

Preoperational: Design and Construction

In a sense our task in considering the design of an irradiation plant is a straight forward one in that we are presented with a set of plans and specifications and are called on to consider acceptance. We know that the plans have already been tried and tested elsewhere - the plant in Australia is not a world first. None the less because changes do occur (viz. size of space available; soil density variations, etc.) we still need to go through the process of calculating shielding requirement and ascertaining how our calculations - or more exactly our results - compare with the plans as submitted. The calculations are, in themselves not immensely difficult in that there is a certain similarity to the calculations made for the cobalt therapy situation - the difference is that the source is nearly three orders of magnitude more active and its considerably less of a point source so that applying formulae based on inverse square

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law relationship introduces another error very much on the side of safety. Once all this has been done, as far as we are concerned, construction can proceed.

A gamma irradiation plant does not, of course, only rely on concrete for safety. It requires a collection of other devices to ensure the safety of operating personnel, and it is often the efficiency of these devices that will decide whether you are going to have an accidental - and possibly fatal - radiation exposure during the life of the plant. No amount of metre thick walls will protect the operator if he can just open the door and walk in while the sources are exposed.

Because of the need to prevent accidents several independent safety systems are generally incorporated into the one facility. These would include:

1. an electrical/magnetic system for locking the entrance door to the irradiation area;

2. a fail to safe system on the device for hoisting the source from the water;

3. a radiation monitoring system;

4. an entrance security system which defines an entry protocol.

Each of these systems is able, independently, to prevent access to personnel exposure either by preventing entry or by dropping the source into the shielded position, yet the systems are so inter-related that it is not possible to cut out or bypass one without causing the others to fail.

Just a few words about each of these:

The first - an electrical/mechanical door lock is perhaps the most obvious and simply means that the door to the

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maze leading to the irradiation chamber can only be opened if the source is in the shielded position. If an attempt is made to open the door while the source is exposed the power to the hoist mechanism is cut and the source will be lowered into the pool. -

The fail safe hoisting system simply indicates that in the event of any power failure or structural defect (say a support cable snapping) the sources will again be automatically lowered.

There are several radiation monitors throughout a system and they will on the one hand indicate radiation levels on a meter and - probably more important - activate a system of warning lights to show that the source is either exposed or shielded. Failure of the lights will cause the system to fail to safe - that is the sources cannot be exposed.

The entrance security system is perhaps one of the most important safeguards of the whole system. It means that if you want to expose the sources or if you want to enter the radiation area a definite protocol of steps needs to be followed. In other words if you are ready to irradiate some material you don't just close the door and push a button. A definite sequence of safety orientated steps need to be followed or the source simply will not expose. Conversely if the irradiation procedure is completed and you wish to enter the bay you again need to follow a definite sequence of steps.

Thus, effectively four separate systems ensure the safety and security of the facility.

In fact the most important aspects of a safety system are not so much how many you have but how they relate to one another. That is to say, what a proper integrated system requires is:

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1. redundancy - that is, duplication of components to ensure proper operation of a system to the extent that it will fulfil its function even if some components fail;

2. independence - that is one systems operation shouldn't depend on another;

3. segregation - that is, systems performing a similar function should be physically separted to avoid the chance of concurrent loss of function from external sources;

4. diversity - not all safety systems should work the same way - that is differing designs, operations and manufactoring methods should be used.

Operation

The safe operation of an irradiation facility of this type depends on three basics. These are:

1. an appreciation of the in built safety systems;

2. adequate training of personnel; and

3. the existence of an emergency system.

A few words on each of these.

All safety systems, no matter how good, depend on the respect of the users and on adequate maintenance. It is often easier to bypass or override a safety system than it is to use it and clearly that is where you have stage one of a disaster. It is only if personnel are adequately trained and a system is properly maintained that this can be avoided.

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It is not always easy to guarantee adequate training because in a situation such as this you have people using a massive radiation source yet essentially all they are doing is to supervise a process - they are not radiation workers in the sense in which we generally understand the term (for example diagnostic, therapeutic or industrial radiographers or research scientists all of whom actually work with and generally manipulate sources of radiation). These people, hopefully, never get near the sources they work with and have little cause to have anything to do with them - source changes are generally carried out by the suppliers as are any service or maintenance calls that involve the sources.

Because of this the units are generally operated by personnel who do not have a history of radiation experience and they require training to familiarize themselves with what radiation is all about, what its being used for, what are its hazards and how can it be kept safe. But above that they must have instilled in them a healthy respect for the correct operatering system of the facility.

A second important aspect is for an organisation to have an emergency system that can respond to accidents that may arise. What kind of accidents can occur? There are a few that should be considered and these include:

1. fire inside the irradiation bay - some materials being irradiated are inflammible and hence fires are not impossible;

2. source becoming stuck in the exposed position;

3. sources falling out of the exposure frame either during source changes or later because of poor fixing in place (this is another reason for needing monitors to ensure that a source pencil is not lying around the place);

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4. general accidents involving sources during transport, storage, installation or removal;

5. breakdown of one or more of the safety systems.

Again the avoiding of accidents depends on adequate training of staff and religious adherence to a safe working procedure but the unexpected accident that may occur requires that an organisation have a response plan and have access to personnel who can help in such a situation. Essentially in New South Wales assistance tends to be available from a combination of, on the one hand, the company itself and the suppliers of the equipment and, on the other hand, offices such as my own which has an emergency response responsibility.

Accidents are often the result of pure mischance but also often also as a result of a breakdown of an operating system. In a gamma sterilization system, for example, with its immense radiation levels insulation on electrical wires only has a limited life (the plastics go solid and flake off) and if they aren't regularly replaced electrical short circuits will occur. Maintenance of this type may appear to be self evident but without proper wiring a system cannot operate properly and this form of maintenance is just one that requires constant supervision. Another, is that lubricants will often break down under the radiation exposure levels and, again, maintenance is the secrete of safe operation.

In other words, we may not be able to make an accident impossible but by enough attention to detail we can go a long way towards doing so.

To conclude, the safe operation of a gamma irradiation facility depends on a combination of preoperational steps - design and construction - with a properly developed set of operational procedures.

LECTURE 29

THE PRINCIPLES OF PACKAGING

D. HARTLEY

THE PRINCIPLES OF PACKAGING

Derrick Hartley

Introduction

I started my working life as an analytical chemist. I have worked in this capacity in the oil, pharmaceutical and food industries. Whilst in the food industry I became interested in packaging and for the last 12 years I have specialised solely in packaging so much so that I have become involved in the teaching of Packaging at Sydney Technical College in my extra work activities.

I am also the N.S.W. tutor for the Australian Institute of Packaging correspondence course. I have worked for a flexible packaging printer and converter and I am Packaging Research Supervisor for Arnott's Biscuits in charge of their extensive Packaging Research laboratory at their Research Centre in Homebush. In such a capacity, I am involved in a wide range of packaging materials and test methods. Arnott's Research Centre is not only involved in researching into packaging but also into food processes, analysis, microbiology and biochemistry etc. All these functions interrelate with each other. This serves as an introduction and gives you some background as to how I fit into the Australian Packaging scene. In this lecture I will concentrate on flexible packaging since the theme of the Course is on a subject which lends itself particularly to flexible packaging but the following principles also apply to other form of packaging.

Why is packaging necessary

Packaging in one form or another is taken for granted by modern society. If we were to stop and think about packaging in a little more detail, it may on first appearance, be a mystery subject. The range of materials which are available is ever increasing. We will examine such a list later on. It need not be a mystery subject. If we examine how packaging has evolved, this picture becomes clearer. One hundred years ago, packaging was fairly basic by today's standards. Similar needs to today's requirements were considered, the difference being that today we have a wider choice of materials and more control on seal integrity of packages.

Packaging is necessary to:

(a) protect,

(b) preserve,

(c) contain,

(d) inform.

Depending on the product, the package may be required to fulfil only one of these functions or perhaps more. We will look at each one of these requirements in more detail.

Protection in package

There are many ways in which a package may be designed to protect a product. We must consider what areas of protection we require.
We may wish to protect the product against:-

(a) External odours and taints migrating into the package. Here we would choose materials which act as barriers against odours.

(b) Aroma loss. Again we would choose barrier materials.

(c) Insect infestation. Some packaging materials, i.e. p.v.d.c. coated regenerated cellulose film, whilst offering protection against aroma egress or ingress of undesirable odours provides little resistance to attack by some insects. These insects can easily eat into and penetrate the package.
Such materials as polypropylene, polyester, and foil laminations offer varying degrees of insect infestation protection.

(d) Light. Some reactions are induced by light, IR, Visible or UV, i.e. oxidative rancidity.

(e) Atmospheres - oxygen, carbon dioxide, nitrogen. In controlled atmosphere packaging, it is necessary to prevent gases from migrating both in and out of the package. For example, in the packaging of peanuts, (or any other fat or oil containing product), a rate determining factor in the shelf life of the packaged product is the rate at which the oil/fat present in the peanut becomes rancid. The action of heat, light, moisture, and oxygen cause an oil/fat to become rancid. By the reduction or elimination of oxygen, this process can be checked and consequently the shelf life of the product extended.

There are several methods whereby we can control the atmosphere inside a package.

(i) Oxygen scavengers. Here, a gas permeable sachet containing a ferrous complex is inserted inside the pack prior to sealing. The ferrous complex reacts with oxygen inside the pack thereby reducing or eliminating the quantity of oxygen available for reaction with the oil/fat present in the product.

(ii) Gas flushing. Here the air normally present in the package (containing approximately 20% oxygen) is replaced with an inert gas such as carbon dioxide, nitrogen or a mixture of both.

(iii) Vacuum packaging. Here all the air in the pack is removed, thus reducing the amount of available oxygen present.

Packaging materials do allow gases to transfer to a greater or lesser extent. The rate of this transfer for the various packaging materials must be known for the gas systems involved before the correct choice of materials can be made.

In some cases, i.e. fresh fruit and vegetables, it is desirable to have packaging materials which allow the product to respire where oxygen can pass into the package and carbon dioxide out of the pack at controlled rates.

Coffee bean packaging is another example where carbon dioxide is allowed to escape from the package at a controlled rate. Specially vented packages are used which do not allow more than is required to be expelled since aromatics necessary for flavour must be retained.

In fresh meat packaging, oxygen must be present if an attractive red colour is to be maintained. Again, these requirements must be fully understood if the correct choice of packaging material is to be made.

(iv) Alcohol atmospheres.

Another method of controlled atmosphere packaging which has been used by the Japanese for centuries is that of controlled release of ethanol vapour inside a package containing high water activity foods. It is only recently that the mechanisms of this principle has been understood and commercial use made of this. Such products as "Antimould 102" and Ethicap have appeared on the market. These products are sachets which are made of an ethanol permeable membrane. The sachet contains a mixture of ethanol adsorbed on silicone dioxide.

This sachet is placed inside a package containing a high water activity food, i.e. madiera cake. Ethanol is released into the atmosphere at a controlled rate. Under normal conditions mould would appear on the surface of the cake towards the end of a relatively short shelf life. However, with the introduction of the sachet containing the correct weight of ethanol, mould growth is inhibited. The Japanese used this principal in bygone days by incorporating a cloth sack containing fermenting grain when preserving rice cake, a high water activity food.

(v) Temperature reduction.

Chemical reaction rates are temperature dependant. When the temperature is reduced, the rate of reaction is also reduced. Use of this is made in the refrigeration down to 4^{o}C in the extension of shelf life and therfore preservation of many foods. Freezing down to -20^{o}C further extends the shelf life. The effects on packaging materials and an understanding of the atmospheres under these conditions is essential when utilising these preservation techniques.

(f) Moisture ingress or loss. This is probably the major rate determining factor in shelf life evaluation. Most food products change in their characteristics when the moisture content changes. Water activity (or equilibrium relative humidity) is probably a more practical property of the product to the packaging technologist rather than moisture content. It is a property which, until recently, has not been given enough attention. With the advent of more reliable electronics and sensors, water activity (or equilibrium relative humidity) of a product can readily be measured and is important when predicting moisture transfer potential. Moisture content is of course important when looking at moisture transfer rates. The majority of packaging materials do allow gaseous moisture to transfer to a greater or lesser extent and knowledge of this rate for the various packaging materials is important when designing a package and generally is well documented. Either static or dynamic methods are available in the determination of water vapour transmission rates (W.V.T.R.) The dynamic method uses electrolytic sensors and the method gives results in a matter of hours whereas the static method which has been the workhorse of the packaging industry for decades is time consuming sometimes taking up to a week for the higher barrier materials. The dynamic method is also much easier to use and the chance of error is less in the hands of a proficient operator. Results are quoted in $g/m^2/day$ at the conditions which the experiment was conducted (except in U.S.A. where g/100sq. inches per day is quoted). The conditions used for this test are normally tropical conditions, 38°C and 90% RH. Temperate conditions of 25°C and 75% RH are also quoted and in Europe (DIN 53122) 23°C and 85% RH are quoted. For further information on this test method, A.S.T.M. 96E and B.S.3177 should be referred to.

Moisture loss control is important for high water activity products where moisture loss results in either crusting or hardening of a product, e.g. crumpets, pastries and cakes. A level of moisture loss is sometimes necessary to prevent condensation on the inside of the package where mould growth may be promoted. Moisture gain control has two areas of consideration. Moisture gain may result in a product losing crispness and becoming soft e.g. chips or biscuits.

Moisture gain of some products, however, may not result in textural changes but may result in allowing the water activity to increase to a level where mould and fungus growth is possible causing product spoilage.

(g) Physical protection. This is not normally a consideration in flexible packaging. Some protection can be given by, occluding air (or gas) inside the pack. This air creates a pillow if the pack is hermetically sealed and when a multiple of these packs are placed inside a carton, the occluded air does provide some physical protection. This is particularly useful when packaging fragile products like potato chips or extruded snack products. The packaging machine - usually a vertical form fill and seal machine, can be designed to include air rather than expel a certain amount prior to sealing.

Preservation in a package

I have already mentioned some areas where extension of shelf life can be achieved by using a combination of barrier materials and controlled atmosphere thus slowing down internal chemical reactions. This falls into the combined activity of protection and preservation.

Preservation of food product can also be achieved by some form of secondary processing. One of the most common forms of achieving this is sterilisatrion by heating the principle developed by Aperte in the early 1800's and is still used today in the canning industry. The food is hermetically sealed inside a metal can and the whole package is steam heated under pressure to 120°C for a time which has been calculated to ensure that the centre of each pack reaches this sterilising temperature.

This process is also referred to as autoclaving. The exposure time is inversely proportional to the temperature used. Accurate time calculation is necessary in order to prevent overcooking of the product. The principle behind this preservation process is simply to destroy all microorganisms present and to ensure that no micro organisms can penetrate the package during the shelf life of the product. This principle can be achieved in ways other than using heat for total sterlisiation. Aseptic packaging is a development of this and is proving popular in the fruit juice industry. Trade systems include Combibloc and Tetra-Brik. This system uses a flexible packaging barrier laminate which is chemically sterlised (or U.V. sterilised) prior to the forming filling and sealing of the package. The product being filled has gone through a process of pasteurisation. U.H.T. milk is also packaged in a similar manner. The advantage of this system over canning is that the total package is lighter thus reducing transport costs and the product does not denature as much due to cooking as is experienced in the heat sterilisation of the canning process even though heat is still used to sterilise the product. This is due to the fact that more control on the temperature/time relationship is possible in pasteurisation and the temperature of the product is raised and lowered very quickly, quick enough to kill between 97-99% of the spoilage bacteria but not long enough to cook the product. By reducing the spoilage rate, the shelf life is thus extended. This process, although extending the shelf life of a product, does not give an infinite shelf life as does the canning process. Radiation is another form which can be used to preserve a food product. There are several types of radiation sterilisation. The subject can be divided into two forms, non-ionising and ionising radiation. In non-ionising radiation, this is usually a surface effect, and can be further subdivided into two types, infra-red and ultra violet radiation. Infra-red generates heat on the surface and kills bacteria by increasing the surface temperature, whereas ultra violet kills bacteria without increasing the surface temperature.

Ionising radiation is lethal to micro-organisms because of its destructuve effect upon the contents of living cells. Again there are two types, high energy radiation and gamma radiation.

High energy radiation is produced by electron accelerators and has relatively low penetrating power and is suitable for sterilisation of small articles and thin films. Gamma radiation derives its source from such radioactive chemicals as Cobalt 60, it is more penetrating and is proving to be a versatile source of sterilisation.

Sterilisation is effected after the package has been hermetically sealed.

Of these four radiation methods, gamma radiation is probably the most effective and economical. The equipment, however, is expensive and experienced operation is essential. Consumer acceptance may be another hurdle, but I see this only as a matter of time.

If we look back to when the electric light was first introduced as a method of lighting a room, signs were displayed in hotel rooms using this new invention -

> "This room is equipped with Edison Electric Light. Do not attempt to light with match, simply turn key on wall by the door. The use of electricity for lighting is in no way harmful to health, nor does it affect the soundness of sleep."

We may laugh at this now but it was a serious business at the time.

A more recent example is the use of microwaves for cooking. There was much speculation at the time of introduction but it is considered a normal method of cooking in the home now. So, I believe that ionisation radiation will be accepted as a method of packaged food preservation. There may still be a few learning problems but these will be overcome.

In the March 1984 edition of Food and Drug Packaging, it was reported that "F.D.A. rules would pave the way for food irradiation". The F.D.A. was considering requiring irradiated foods to declare, "Treated with Ionising Radiation" on the principal display panel of the label. This statement may cause alarm to people initially especially with all the anti-nuclear feeling currently present and therefore I feel consumer education will be necessary if such a system be adopted here. It is worth noting here that gamma radiation may have an effect on the packaging material; for example paper is weakened, chlorinated organic materials such as PVC and PVDC liberate HCL and glass is temporarily darkened. Other methods of food preservation include inhibitors such as acetic acid, sulphur dioxide, salt curing and the use of syrups for water activity control. Cooling and freezing was mentioned earlier as was controlled atmospheres.

<u>Containing in a package</u>.

A package may be required to contain a fixed weight or volume of a product for distribution, hence removing the need for weighing or measuring at the point of use. By containing smaller portions of the product, the product is less likely to be contaminated than if a bulk distribution system was used and the shelf life of the product is extended.

<u>Information on a package</u>.

A package is a useful medium for displaying information. This information may be of the very basic, i.e. informing of the contents or weight, or it may be to inform on how to use or reconstitute the product through to marketing by visual impact. Here, the choice of packaging materials and choice of printing is of relevance.

All of the abovementioned factors must be considered when designing a pack and choosing the materials of package construction. Other factors which must also be considered here are:

(i) type of packaging machinery available,
(ii) speed of packaging operation,
(iii) method of forming and filling of the package,
(iv) possible interaction of the packaging material and the product.

(v) possible interaction of processing and the packaging material.
(vi) climatic or environmental conditions under which the package will be exposed.
(vii) the distribution system to which the package will be subjected.

General Considerations

In any packaging situation where shelf life is a consideration and the barrier characteristics of the packaging materials used, contribute to that shelf life then seal integrity of the package is of paramount importance. Therefore some method of evaluating the seal integrity of the package and giving this a numerical value in terms of efficiency is essential if product integrity is to be assured at the termination of shelf life. In situations where moisture uptake of the product is the rate determining factor for shelf life, a commercially acceptable machine seal efficiency may be as low as 85%. This means that 15% of the moisture over the shelf life period is passing into the pack through the seal and 85% of this moisture is passing through the wall of the pack. For packages which rely on a sterile environment, then a 100% seal efficiency is essential and this efficiency must be assured for all packages produced.

If a secondary processing is used to sterilise the package then this process must be taken into account when choosing packaging materials. Tests on these materials must be performed and possible interaction of the product with the packaging or breakdown of the packaging during processing. For example as mentioned earlier gamma radiation release Hydrogen chloride from polyvinyledene dichloride (p.v.d.c.), the barrier and heat seal coating on cellulose film.
Packaging can be considered as a marriage between material, product, process and machinery. All of these are dependent upon each other. If the packaging machinery cannot handle the material chosen at the production speed, then imperfect packages are formed and the product will break down in storage. If you have the perfect product, and an inadequate material has been chosen, then the product will break down

etc. I use the philosophy of overpackaging on a new product development because quite often in this situation you are breaking new ground. Accelerated shelf life testing whilst useful in this situation can often be misleading. If a product fails due to some unforeseen factor and this product reaches a consumer, then the result can be serious. I liken this situation to that of going to a new restaurant. If the food at a restaurant is "off" for whatever reason, and you have had an unpleasant experience, then would you go back again to that restaurant? I think not. You may not complain either so the restaurant manager may never be aware of a problem, the only sign being that business did not expand as much as it may have done should things have been satisfactory.

When the product has been launched in prestine condition we then have the time and possibly more experience with the product to fine tune the packaging material to the situation.

I have another philosophy - don't blindly copy a competitor. It is very tempting to look at a product which may be similar to your own, to look at the packaging material and say to yourself, if they are packaging this way it must be right. I call this the "blind leading the blind" approach. Who is to say that the original company were technically competent, or that their processing or distribution is the same. Look and consider your opposition company's ideas by all means but also evaluate them in exactly the same way as you would a new development.

Materials used in Packaging

There is an ever increasing range of materials used in packaging, particularly flexible packaging. There is also an increase in the use of semi rigid plastics packaging materials with the advent of coextrusion in this area. This must also be considered as a packaging medium.

The problem which the modern packaging technologist faces is keeping up to date with new developments. In order to develop a package correctly, it is essential that a deep understanding of the properties of the materials available be known. Packaging materials are becoming more complex and production speeds are ever increasing further emphasising the above statement. The better the understanding, the more efficient the choice of material. The packaging technologist must also understand fully the range of coatings and printing procedures available as a converter tailoring tool. He must also understand the product and production procedures used and the interrelation between these parameters. Unfortunately for modern industry, packaging is considered a necessary evil by the unenlightened. A few forward thinking companies, however, and it is only a few at this stage, are realising the significance, cost and importance that packaging has to play in the overall performance in a company. These companies have developed a function within dealing solely with packaging and its related problems in a similar manner to the way the marketing function has been developed.

Bearing these points in mind, I will list a few of the basic packaging materials in common use:-

Paper
Polyethylene
(H.D.P.E., M.D.P.E., L.D.P.E., L.L.D.P.E.)
Polypropylene (cast and coextruded and coated B.O.P.P.)
Aluminium foil
Metallising
Cellulose film (P.V.D.C. coated)
E.V.A.
T.P.X.
P.V.C.
Nylon (6, 6.6, 11, 12)
Ionomer
Polystyrene
Polyester
Polycarbonate
Cellulose acetate
Vinyl chloride acrylate
Ethylene acrylic acid
Ethylene methacrylate
Ethylene vinyl alacohol.

As you can see we are beginning to become complicated. When we consider the possibility of lamination and coextrusion the possibilities become almost limitless. We do not have enough time to delve into the properties and characteristics of each of these materials. Thank you.

Derrick Hartley

Derrick Hartley, M.Inst.Pkg.(Dip); F.A.I.P.; L.R.S.C.
April 1985

LECTURE 30

INTASEPT - THE NEW BAG-IN-BOX ASPETIC FILLING SYSTEM FOR HIGH & LOW ACID LIQUID FOODS

I. ANDERSON

"INTASEPT - THE NEW BAG-IN-BOX ASEPTIC FILLING SYSTEM FOR HIGH AND LOW ACID LIQUID FOODS"

MR. I. ANDERSON - WRIGHTCEL LIMITED

The growth of bag-in-box packaging of liquids has been one of the most spectacular packaging developments of the past decade and nowhere has it been more spectacular than in Australia, where it revolutionised the wine industry.

In the early 1970's, wine consumption in Australia stood at a little less than 7 litres per head per annum. Today, the figure is 20 litres per head per annum with almost 60% of total wine sales now packaged in this form.

Wrightcel Limited were pioneers in this development, through their development of a suitable laminate structure based on a coated nylon film substrate and L.L.D.P.E., as the sealing web. They gained the licence to sell and manufacture the Waddington and Duval press tap in Australasia and built a very good commercial system.

Since then, many other liquids have found their way into bag-in-box, using an enormous variety of taps, plugs and closures. However, with few exceptions, all these systems suffered from a common fault - poor shelf life because of the problems associated with oxygen ingress. We knew that most of the oxygen problems emanated from the gland/tap area and we recognised that, if these fitments could be isolated from the product by some means, the oxygen permeation would be significantly reduced.

After much discussion and thought, we decided to try to evolve a system which would ensure that the product shelf life would be increased greatly, whilst at the same time, ensuring that the filling operation was not effected in any way.

A list of all the parameters considered to be essential to such a system was drawn up, and a study group appointed to work on a feasability study. After a number of meetings at which various solutions were put forward, the simple solution to the problem came from Lee T. Mellett, Technical Director of Wrightcel Limited.

He reasoned that, as the weak spot in the bag was the gland, for it was a known fact that most of all oxygen ingress occurred through the gland area, i.e. either directly through the gland itself as well as through the tap and the tap/gland interface, that we should simply put a patch of material with at least the same barrier properties of the material from which the bag was made, over the gland hole cut-out, and heat seal it inside the bag after the product has been filled into the bag. It sounds very difficult, but in practice, it has not proven too hard to do.

Firstly, we reduced the gland size (remember we were at this time aiming the result at the wine market), and to the back of the polythene gland, we partially affixed a circular piece of the bag material by heat sealing it in three places. The gland, with the membrane attached, was then heat sealed into the bag in the normal way. When the gland was offered to the filling head, we found that product flowed quite well past the membrane, which flexed sufficiently to allow free passage of the product.

At the end of the filling cycle, and while the gland is still attached to the filling head, a heat sealer operates from the back of the bag, sealing the membrane to the back of the gland. Because the "back" web of the membrane material consists of a film which is incompatible to heat sealing to polythene, the back layers of the bag do not attach to the membrane; even though they do heat seal to themselves. In this way, the hole cut into the bag into which the gland is placed, is "patched" with material of similar barrier properties to the bag films and thus, the increased barriers to O_2 lengthen the shelf life of the product by as much as 75%.

This system was labelled "Wrightseal" (Reg. Trade Mark).

The Wrightseal system never achieved its purpose of taking Wrightcel to top supplier to the wine industry in Australia, because before the development was completed, the wine packers engaged in a price war which saw shelf life deposed as the primary object in favour of price. The simple one piece tap was much cheaper and it took over, in various forms, and still holds sway.

However, "Wrightseal" found favour in several wineries in California and British Columbia and for hot filling fruit juice in Australia, U.K. and Africa because of the fact that the sealed membrane keeps the hot juice away from the tap which would otherwise be badly effected by the heat unless made from heat resistant polymers, in which case it simply becomes too expensive to use.

At this time (early 1982), I became Development Manager of the Liquid Packaging Division at Wrightcel, with the specific task of maintaining and directing the development of the Wrightseal system.

As a food technologist, I was very aware of the great commercial advance being made by the most dominant form of aseptic packaging at the time, the brick packs of the Tetra-brik and Combibloc. Like other bag-in-box manufacturers, we had been looking at extending our conventional systems to enable aseptic filling of bags but, like the other manufacturers, found the deficiencies of the available technology, which was really an extension of laboratory clean room technique, gave problems in assurance of truly sterile packaging.

The Wrightseal system of filling and sealing gave us the means to by-pass the conventional technology in one simple step. Of all the bag-in-box systems being promoted, only the Wrightseal method would allow for the product transfer to be carried out without exposure to the external environment.

So the INTASEPT - (Reg. Trade Mark) system of aseptic filling of bag-in-box was conceived and now we are able to offer this world first to packers to enable them to achieve worthwhile savings in cost, whilst at the same time presenting a better product to the customer.

Now, let us look at the principle of the Intasept system in closer detail.

Aseptic filling is simply providing a means of transferring a commercially sterile product from a closed environment (in this case, a sterile pipeline) into a sterile container, under sterile conditions and sealing that container to prevent the ingress of contaminants in subsequent handling.

With the Intasept system, we achieve this by placing another membrane over the top of the gland of an otherwise standard Wrightseal bag, fully sealing it and then subjecting it to gamma radiation to sterilise the bag. This, then, assures the internal bag surfaces remain sterile despite subsequent handling in normal ambient conditions.

The aseptic transfer of product is achieved by offering the bag up to the filling head where the top membrane forms the "floor" of a sterilisable chamber between the membrane and to the actual fill valve itself. This interspace is sterilised by steam, in the case of high acid (fruit juice) filling, or a combination of steam and heated hydrogen peroxide in the case of low acid products (milk), although we are hopeful of developing the system to the use of steam only in the very near future.

A cutter integral with a fill valve then punctures the top membrane, the product proceeds via the now sterile pathway into the bag, a small burst of steam follows up the product to chase the remaining product into the bag and then the bag is sealed, as in normal Wrightseal systems.

The essential point is that, at no time during the transfer process, is the product pathway exposed to the external environment. The transfer is achieved in a closed system and the sterile container is heat sealed, providing a fully sealed unit to which a dispensing device can be added if desired.

To explain the system more fully, the attached figures are extracted from our patent material. As in all patent drawings, full detail is not supplied but, in practice, it works as follows:-

1. Lower membrane 5 is only partially circumferentially sealed to gland 8. This provides a passage for product via 7 into bag. Sealing is achieved by application of heat sealer to back of bag at 1 to complete circumferential seal at 9. The interface of 5 and 1 does not heat weld due to differential materials used and 1 lifts away from 5 after heat sealer is retracted. This is the basis of the Wrightseal sealing system.

2. There is a steam barrier between seals 29 and 30.

3. Shaft 27 terminates at the lower end in a four bladed cutting head and at the upper end with a small piston.

4. This piston is actuated by steam entering 47 and returned by positive pressure in space 24 on flush sequence. This obviates requirement for bacteriological barriers in fill piston internal mechanism.

5. Port 44 leads to external bellows sealed valve.

6. Steam entry for sterilisation is via port 25, exhausting through 46 to 44 and then to atmosphere. Pressure drop is approximately 4 bar at 25, 3 bar at 24, average 1.5 bar at 46 and 44. This gives adequate kills at 2.5 to 3 seconds with expected load levels. A violent scrubbing action from steam passage also physically removes ambient air from area 46.

7. 21 is product entry port.

8. Entire fill valve and product pathway is initially steam sterilised by placing a solid fitment replacing membrane 41. This operation can be carried out at any time in filling shift, independently of upstream equipment if required, using steam supply to machine, or in concert with plant sterilising sequence.

The system has some very valid advantages over opposition development, in particular:-

1. Pre-sterilisation of line, equipment and fill valve components is very simply carried out and is most positive.
2. The filler is easily installed and does not require any specific factory environment.
3. Energy requirements of the system are minimal.
4. The fully sealed membranes are positive sealing systems and proof against ingress of organisms both prior to and post filling. All other systems to date rely on a friction fit component of some type.
5. Operator skill requirements are minimised.
6. No chemical sterilants are used in the process.

FIGURE 1.

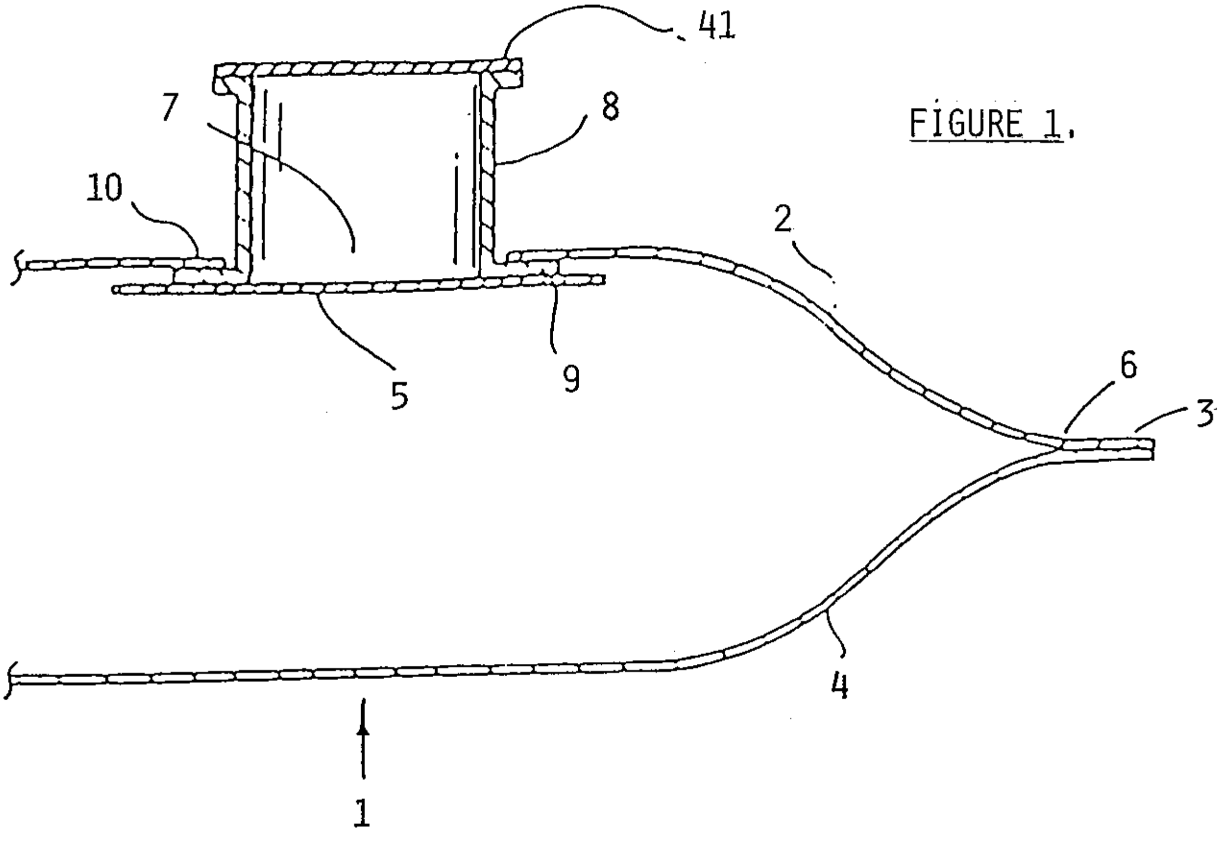


FIGURE 2.

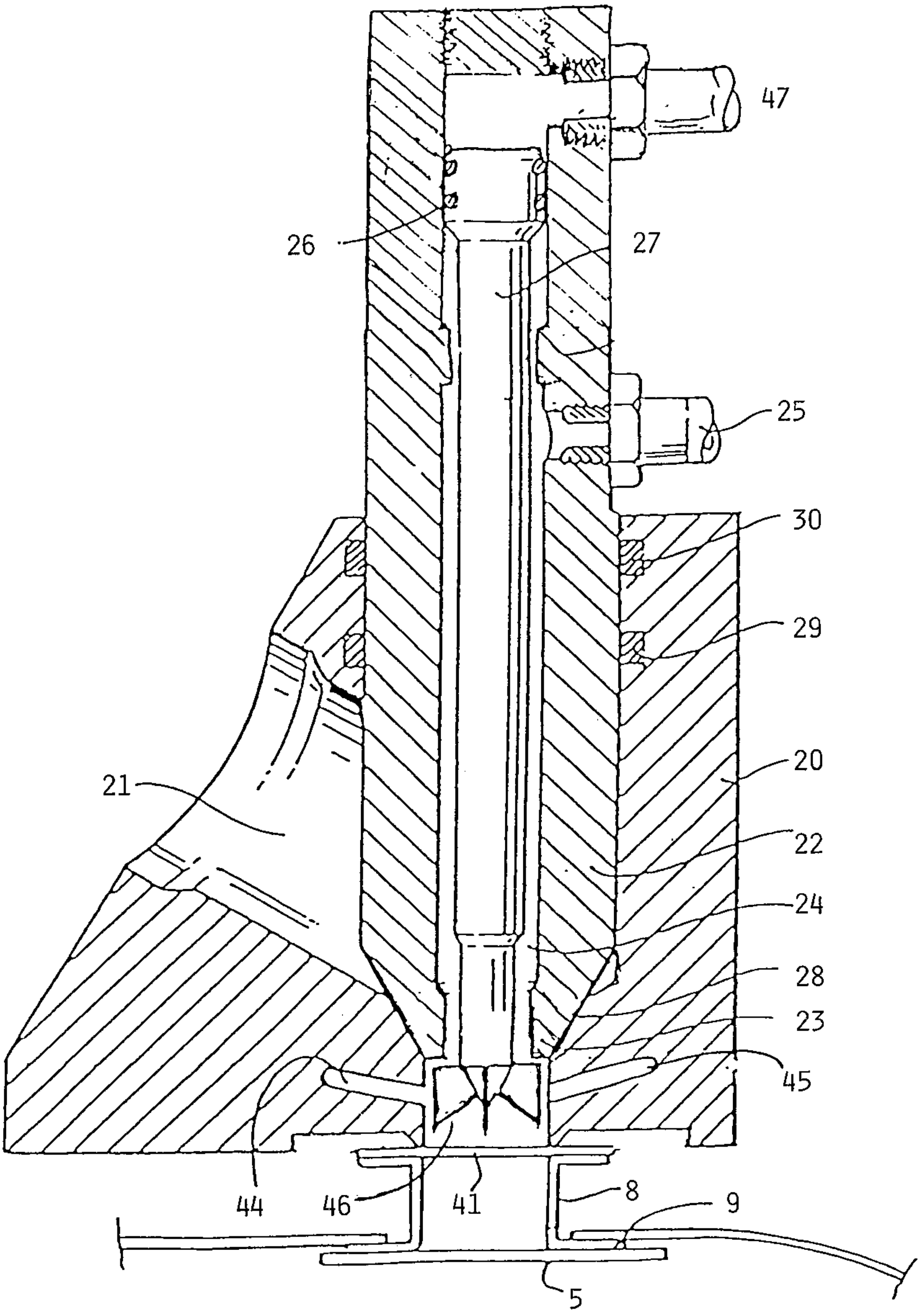


FIGURE 3.

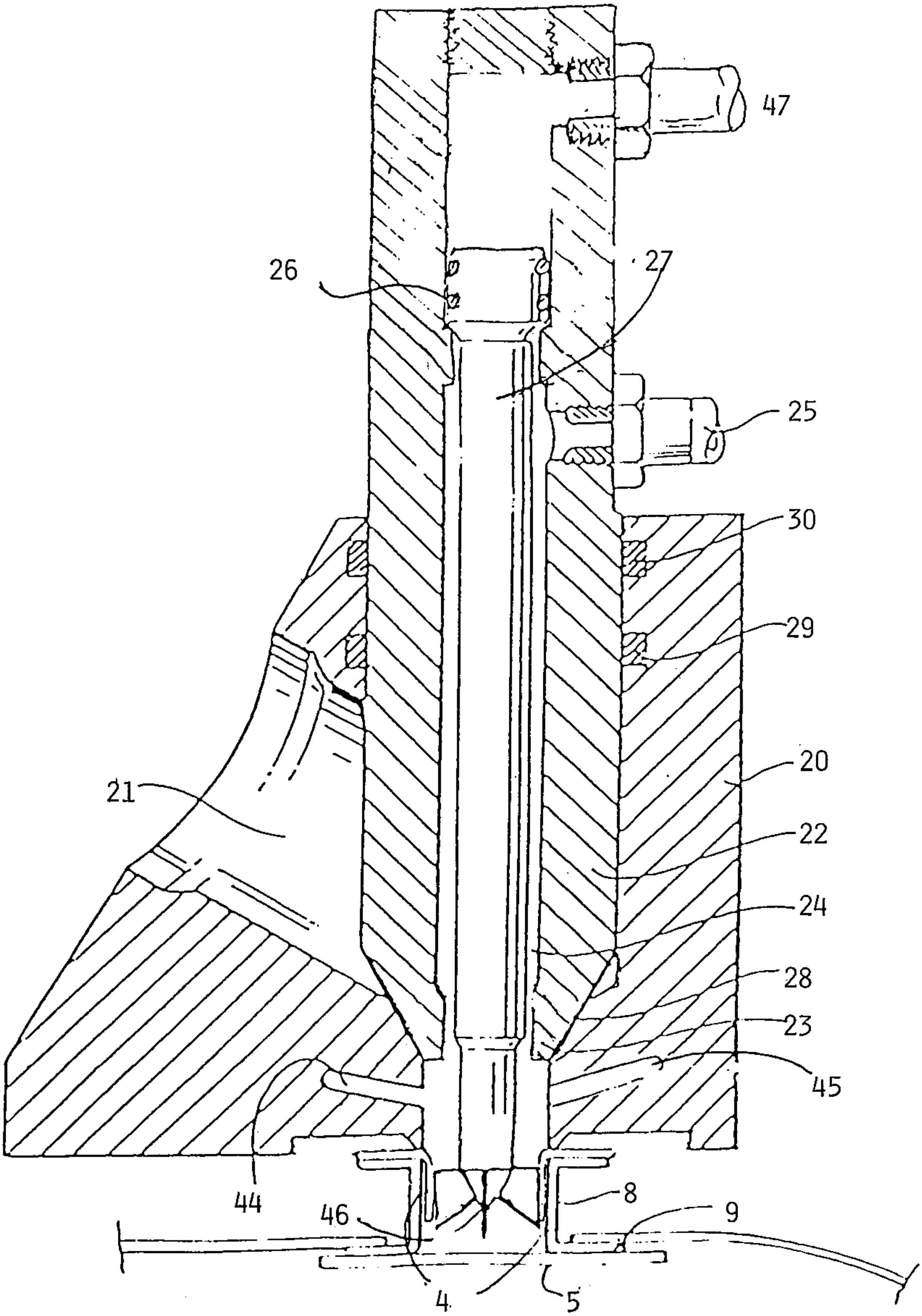


FIGURE 4.

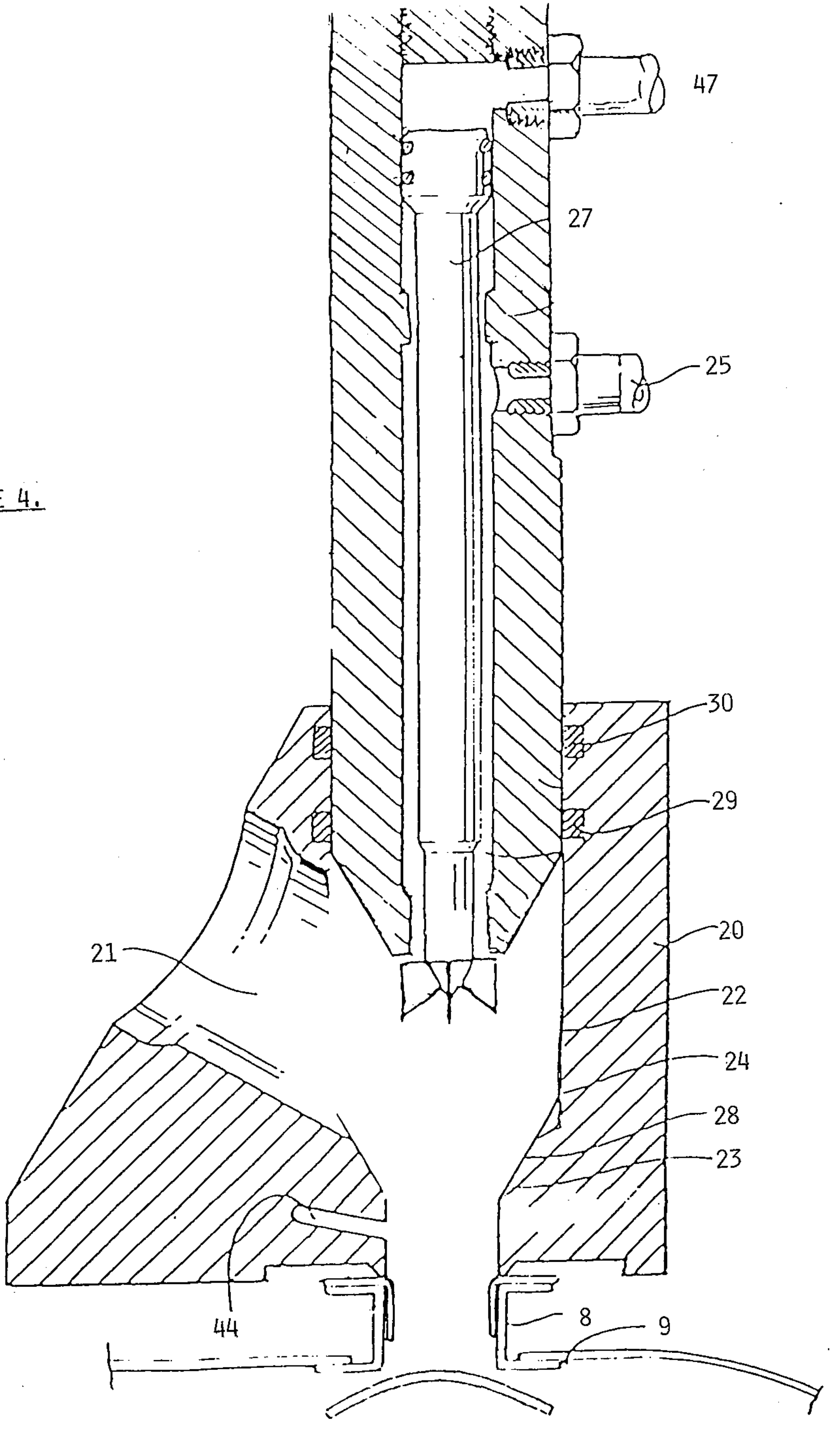
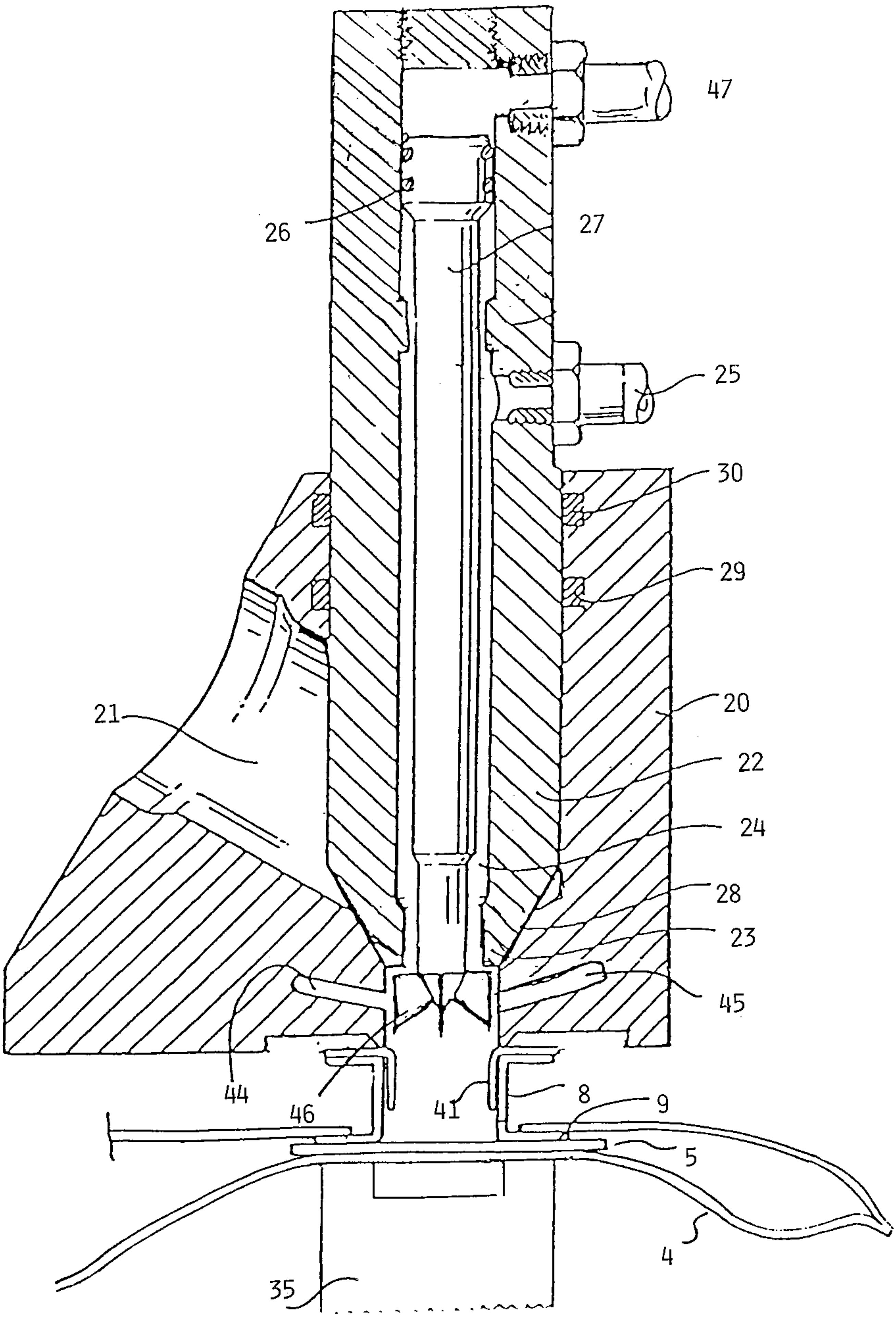


FIGURE 5.



LECTURE 31

CONSIDERATION OF RADIATION EFFECTS IN THE CHOICE OF FOOD PACKAGING MATERIALS

P. MOORE

CONSIDERATION OF RADIATION EFFECTS IN THE CHOICE OF FOOD PACKAGING MATERIALS

P. W. MOORE

INTRODUCTION

The treatment of foods with ionising energy can have several objectives, and involves foods of many types, hence the variety of packaging likely to be encountered is wide indeed. Guidelines published by the FAO/WHO Committee of the Codex Alimentarius Commission state that "the packaging materials shall be of suitable quality, acceptable hygienic condition and appropriate for this purpose and shall be handled according to good manufacturing practices taking into account the particular requirements of the process. The doses applied should be commensurate with the technological and public health purposes to be achieved...". Since no testing procedures are laid down, nor any indication given of the factors to be considered in ensuring that the materials are "suitable", "hygienic" and "appropriate", this does little to reduce the range of materials or limit the conditions.

We may expect that, in addition to satisfying the usual requirements for food packaging materials, it would be necessary to know whether there is any interaction between the food and the package during or after the irradiation, and whether as a result of the irradiation, volatile or leachable substances are released from the pack into the food. Since radiation alters the physical and mechanical properties of many materials, we should have some idea as to whether,at the radiation doses used,there are significant changes in properties such as tensile strength, burst strength, elasticity, brittleness, opacity, colour, abrasion resistance, stress cracking, delamination, corrosion, and moisture and gas permeability. In some cases the pack may need to withstand temperatures of -30° or less. If electron irradiation is used a significant proportion of the energy may be deposited in the pack, and it is therefore important to ensure both that the food receives the correct radiation dose and that the pack is suitably thin yet able to withstand damage due to rough handling. Finally the pack must be of a nature that will prevent reinfection or infestation of the treated food during subsequent handling and storage.

Studies of these aspects have been conducted under USAEC contracts(1,2), and by the US Army (3) and the US Department of Energy using food-simulating solvents with selected packaging materials, mainly plastics, which were irradiated to doses of up to 80 kGy. As a result of this work the US Food and Drug Administration has approved a number of substances for use in packaging materials for food irradiated to specified doses. A list of some materials approved up to 1968 is shown in Table 1.

BACKGROUND CHEMISTRY

In order to appreciate some of the factors which may limit the use of certain packaging materials, consideration must be given to possible reactions involving the common materials used in food packaging. These fall into three groups:

(1) glass and metals,
(2) cellulose-based products,
(3) synthetic polymers (i.e. plastics).

GLASS AND METALS

In this group only the glass jar and the tinplated steel can need to be considered.

Glass is generally unsuitable because it is:

(a) readily discoloured by the radiation, and
(b) too thick for use with electron beam irradiation.

Because the properties that make steel an ideal container for thermally processed foods are often unimportant for irradiated foods the steel can can often be replaced by cheaper, lighter more convenient forms of packaging. With steel cans the radiation effects of importance are those affecting the adhesion, integrity and corrosion resistance of lacquers and enamels used on the internal surfaces of the can. Also, irradiation at sub-zero temperatures may exacerbate any tendency of these coatings to become brittle and cracked. A study by the US Army(3) has shown that the performance of a range of epoxy based coatings was satisfactory for irradiation doses to at least 75 kGy and temperatures down to -90°C.

CELLULOSE-BASED MATERIALS

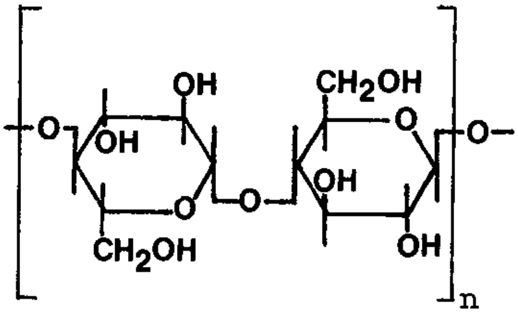
Cellulose and its derivatives are degraded considerably by radiation due to scission of β-glycosidic linkages in the main cellulose chain. The high value of about 10 for $G_{(\text{scission})}$ gives some indication of the extent of this damage. Chain scission, carboxyl formation and carbonyl formation occur in the approximate ratio of 1:1:20(4). These changes are accompanied by increased solubility in water and dilute alkali, and disruption of the structure of the cellulose fibres resulting in a reduction in mechanical properties such as tensile strength, burst strength, wet strength, tear resistance and puncture resistance.

SYNTHETIC POLYMERS (PLASTICS)

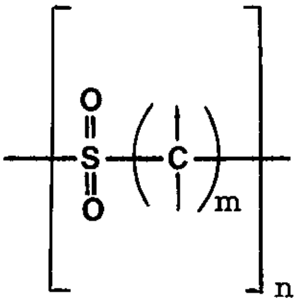
The initial effect of ionising radiation on polymers is cleavage of bonds and the formation of free radicals which may take part in secondary reactions leading to cross-linking, formation of gaseous products (hydrogen, hydrogen halides, hydrocarbons and carbon dioxide), production of new unsaturation and colour centres and (in the presence of oxygen) oxidation and peroxidation. These changes can have a considerable effect on physical properties.

It has been found convenient to classify polymers into two groups according to their response to irradiation; those which predominantly crosslink and those which predominantly degrade by main chain scission.

As might be expected, polymers such as cellulose (I) or aliphatic polysulfones (II) with a repeating labile bond in the chain are very susceptible to degradation.

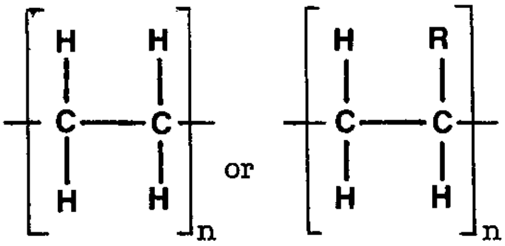


I

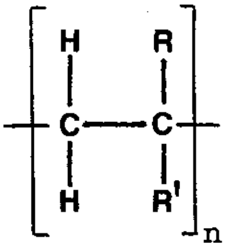


II

For vinyl polymers having structure III (e.g. polyethylene, polypropylene, polystyrene, poly(vinyl chloride) and polyacrylates) the predominant effect is crosslinking; for those with structure IV (e.g. polyisobutylene, poly-α-methylstyrene, poly(vinylidene chloride) and polymethacrylates) the main effect is degradation.



III



R,R^1 = halogen
alkyl
aryl

IV

In some polymers such as polypropylene, nylon and polyethylene terephthalate crosslinking and degradation occur in roughly equal amounts, and the predominant effect then depends upon the conditions. It is often found with these and other polymers that in vacuum or in thick samples in air the polymer preferentially crosslinks especially at high dose rates, whereas the irradiation of thin films in air causes mostly degradation. In air, peroxy radicals are formed by reaction of alkyl radicals with oxygen and these undergo abstraction and disproportionation reactions leading to terminal carbonyl groups rather than radical addition reactions which result in crosslinking. For the irradiation of oxygen-containing polymers such as polycarbonates the result is usually the same in air as in vacuum.

If R and/or R^1 in structures III and IV is a halogen, bond scission results in formation of hydrogen and halogen atoms and evolution of the hydrogen halide.

If R in structures III and IV is aromatic the effect of the radiation is considerably reduced by the ability of the aromatic nucleus to absorb energy. Thus we find that the extent of crosslinking in polystyrene is about 50 times less than in polyethylene, and chain scission in poly-α-methylstyrene is about 20 times less than for polyisobutylene. For some applications additives can be incorporated into the polymer to increase or decrease the radiation effect. The effects of ionising radiation on many of the materials used in food packaging are summarised in Table 2.

THE PURPOSE OF IRRADIATION

In the selection of a suitable packaging material one must keep in mind the purpose of the irradiation treatment because this determines the radiation dose received by the food and the package. Table 3 shows the range of radiation doses approved in various countries for specific treatments of a range of food items. A comparison of information in

Tables 2 and 3 shows that for many materials the irradiation doses used are too low to cause significant, or even noticeable, changes in mechanical properties. For some applications however the performance of certain types of packaging is worthy of a more detailed consideration.

THE PERFORMANCE OF CELLULOSE-BASED MATERIALS

Because of the nature of many of these materials they are used with dry foods or as cartons for secondary packaging. In these applications the effects of radiation on mechanical properties such as tensile strength, burst strength, puncture resistance and tear resistance are of primary interest. Cellulose-based sheets and films can provide an excellent barrier to gas, moisture and odours, and are therefore used as overwraps, heat-sealed bags, and laminated packs for hydroscopic foods or foods with high oil or shortening content. In these applications the production of colour, off-odours and flavours is important.

Tests on fibreboard and paperboard show that property changes in these materials are not sufficient in practice to restrict their use. Irradiation to 1 kGy decreases tensile strength by less than 4%, and tear resistance by 2%(3). Irradiation to 10 kGy at temperatures between 20°C and -80°C decreases puncture resistance by 2 to 7% and burst strength by 2 to 10%. Generally changes are less at lower temperatures. Although irradiation to higher doses required for food sterilization produces proportionately larger changes in properties, these do not impair the performance of fibreboard and paperboard boxes in simulated transportation and shipping tests(5). Irradiation of coated cellophane film to 10 kGy does not produce changes sufficient to limit its use, although at doses of 50 kGy the applications are limited(6).

THE PERFORMANCE OF PLASTIC FILMS

Although changes in mechanical properties of plastic films are reported(7) for radiation doses below 50 kGy there is no known instance of failure of any single-layer or multi-layer film package occurring as a result of this treatment. Nevertheless, tests have shown that some materials are superior to others in performance.

Irradiation to 60 kGy of polyethylene terephthalate/aluminium laminates bonded by an ethylene acrylic acid copolymer to various inner (food contacting) films does not cause delamination or a significant decrease in heat-seal strength. A 20-30% decrease in tear resistance of laminates containing polyethylene-polyisobutylene blend and polyiminocaproyl (nylon) inner layer was however reported(3). Another report claimed improved bond and seal strength resulting from irradiation of nylon/Al/PET laminated pouches(8).

Changes in solubility or leachability resulting from irradiation treatment are possibly of greater interest though less extensively documented. In one test the migration of antioxidant from polyethylene and polypropylene irradiated to 25 kGy decreased into a food-simulating fat but increased into water(6). Other work showed that the migration of antioxidants, plasticisers and tin stabilisers from polystyrene and rigid PVC was reduced after irradiation(6).

An extensive study(3) at the US Army Laboratories with three food-simulating solutions (water, 0.1M acetic acid and n-heptane) in pouches made from nine plastic films (medium density polyethylene, polyethylene-polyisobutylene blend, polyiminocaproyl, polyiminoundecyl, plasticised poly(vinyl chloride) vinyl chloride-vinyl acetate copolymer, vinyl chloride-vinylidene chloride copolymer, polyethylene terephthalate and polystyrene) showed that gamma or electron irradiation up to 75 kGy caused only minor changes in the amounts of extractives which consisted of either monomer, low molecular weight polymer or plasticiser. Extractives were slightly higher for n-heptane than for the aqueous solutions, and were considerably higher for the polyethylene-polyisobutylene film than for the others. Since the instability of polyisobutylene towards ionising radiation is well known it would seem wise to avoid use of this material in food packing applications involving radiation.

The importance of oxygen-impermeable films for certain products is demonstrated by work involving irradiated fish. In one study(9) the shelf life of irradiated fish in polyethylene, polypropylene, coated cellophane, nylon and polyethylene terephthalate was 20 days compared to 30 days or more when packed in cans. Another study showed(10) that polyethylene, polypropylene, cellophane and rubber hydrochloride were unsuitable for packaging irradiated fish because of high oxygen permeability. On the other hand, irradiated uncooked meats may require packages with some oxygen permeability to maintain a normal red colour in the meat.

CONCLUSIONS

Experience shows that, although the physical and mechanical properties of many food packaging materials are measureably affected at the irradiation doses used for the ionising energy treatment of food, these changes are, with a few exceptions, insufficient to prohibit actual use. The selection of suitable packaging therefore depends on the nature of the food, the purpose of the treatment, the conditions of irradiation and storage, an assessment of material leached from the package into the food or lost by the food through the package, physical properties of the packaging material, and of course cost, availability and appropriateness of the package.

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TABLE 1

Packaging Materials Approved by USFDA for Use During Irradiation of Foods

Packaging Material	Maximum Dose (kGy)
kraft paper	5
glassine paper	10
wax coated paperboard	10
nitrocellulose coated cellophane	10
vinylidene chloride copolymer (Saran) coated cellophane	10
vegetable parchment	60
vinylidene chloride-vinyl chloride copolymer film (Saran)	10
vinyl chloride-vinyl acetate copolymer film	60
rubber hydrochloride films	10
polypropylene films	10
ethylene-alkene-1 copolymer	10
polyethylene films	60
nylon 6 films	60
polystyrene films	10
polyethylene terephthalate films	60

TABLE 2

Radiation Stability of Some Materials Used in Food Packaging

Material	Relative Stability	Predominant Reactions (in absence of oxygen)	Observed Effects
cellulose (plain and coated papers, Kraft, paperboard, cardboard, jute etc. coated cellophanes vegetable parchment cellulose acetate	*	chain scission	yellowing, loss in strength, eventual disintegration, embrittlement and reduction in elongation at break in cellulose derivatives.
poly(vinylidene chloride) (PVDC) poly(vinyl chloride) (PVC)	* **	chain scission degradation	darkening, odour, HCl evolved.
vinyl chloride-vinylidene chloride copolymers (Saran) vinyl chloride-vinyl acetate copolymers	** **	crosslinking scission unsaturation	yellowing → brown on standing, HCl evolved, reduction in tensile strength, decreased elastic modulus.
polypropylene propylene/ethylene-vinyl acetate copolymer	*	crosslinking scission gas evolution	embrittlement, yellowing.
ethylene-vinyl acetate copolymer ethylene-butene-1 copolymer	**	crosslinking	reduced elongation at break.
polyethylene	***	crosslinking gas evolution	discoloration, hardening, slightly increased tensile strength, resistance to creep and stress cracking, negligible change in permeability, flexibility and tear resistance.
polycarbonate	***	scission	embrittlement at high doses.
nylon 6	***	crosslinking	hardening, decreased solubility, notch impact strength, elongation at break, increased heat resistance and modulus.
polystyrene	****	crosslinking	slight yellowing at high doses in air.
polyethylene terephthalate (Mylar)	****	crosslinking	slight decrease in tensile strength and elongation at break at higher doses, slight yellowing.
metals (Al,Sn)	****	lattice dislocations	properties unaffected at these doses.

* radiation effects evident at 1 kGy, significant at 10 kGy.
** radiation effects evident at 10 kGy (mechanical properties altered by not more than 20% at this dose).
*** radiation effects evident at 100 kGy (mechanical properties altered by not more than 20% at this dose).
**** essentially unaffected below 100 kGy.

TABLE 3

Food Irradiation Treatments

Purpose of Process	Irradiation Dose Range (kGy)	Food
inhibit sprouting	0.05 - 0.15	potatoes, onions, garlic
delay ripening/rotting	0.5 - 1.0	mangoes, bananas, tomatoes, pears, avocados, pulses, papaya, etc.
insect disinfestation	0.5 - 1.5	citrus, tomatoes, mangoes, papaya, pulses, wheat, rice, dates, cocoa beans, dried fruits, spices
inactivate trichinae	0.1 - 0.3	pork
kill trichinae	2.3 - 7.0	pork
delay cap opening	1.0 - 2.0	mushrooms
extend shelf life	0.5 - 2.0	fruit, vegetables
inhibit mould/rotting	1.0 - 3.0	strawberries
reduce microbial load	1.0 - 2.2	fish, crayfish, prawns
	- 5.0	cocoa beans
	2.0 - 7.0	meat, poultry
	5.0 - 10.0	spices
sterilize special-use foods	25 - 50	meals for hospital patients, astronauts, military, feeds for sterile laboratory animals