FOOD IRRADIATION – GENERAL ASPECTS

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INTRODUCTION

Irradiation of food for preservation or other purposes specifically involves the use of ionising radiations and, in particular, gamma rays from natural or artificial radionuclides, X-rays and highspeed electons produced from electrical machines. Gamma rays occupy part of the electromagnetic spectrum of X-rays; they are identical in nature, the two names being retained to indicate the mechanism of their generation. Such radiations are capable of ejecting electrons from atoms producing positive ions and free electrons which themselves eject electrons from atoms or may become attached to form negative ions. Ionisation and other processes occuring in the atoms of molecules leads to complex reactions and a variety of chemical changes can ensue. The nature and importance of such changes which might occur in irradiated food has been the subject of intense study. It should be made clear that the radiations which are proposed for use are not of sufficient energy to induce any change in the nuclei of the atoms of the elements of food. No induced radioactivity will occur no matter how high the dose applied. The use of the types of radiation referred to, has been long familiar in medical practice, in both diagnosis and therapy; in the latter case in relation to inactivation of viable tumour cells. Not so widely appreciated is the remarkable impact of radiation sterilization as applied to medical devices, particularly plastic disposables, surgical dressings, sutures and pharmaceuticals. In contrast, practical application in the food industry has been small scale and spasmodic and often confined to pilot scale processing and market trials. This is largely due to the question of safety for consumption.

Food processes such as those based on heat, drying or freezing have been accepted as safe largely because of traditional use and even infra-red and UV were readily implemented. Irradiation as a food process was conceived at a time when such treatment was associated with the atom bomb and with induced radioactivity and at a time of increasing awareness of hazards to man through .... contd..

TABLE 1

Doses required for chemical and various biological applications of radiation

Application	Dose Range (Mrad)
Modification of the properties of polymers e.g. polyethylene or PVC	5.0 - 25.0
Long term ambient storage e.g. meat	4.0 - 6.0
Inactivation of Anthrax in hair or fur	2.0 - 2.5
Sterilization of medical devices and pharmaceuticals.	1.5 - 2.5
Sterilization of packaging materials for medical or food use.	1.0 - 2.5
Rendering laboratory animal diets 'pathogen-free'	1.0 - 2.5
Decontamination of food ingredients	0.7 - 1.0
Inactivation of Salmonella	0.3 - 1.0
Reduction of micro-organisms in cosmetics	0.3 - 1.0
Extended storage of meat or fish ($0^{o}C$ - $4^{o}C$)	0.2 - 0.5
Prolongation of fruit storage	0.2 - 0.5
Control of parasites	0.01 - 0.2
Control of insects	0.01 - 0.2
Inhibition of sprouting e.g. in potatoes	0.01 - 0.02
Increase in mutation rate in seeds and plants	0.001- 0.01

To convert Mrad to kGy multiply by 10 i.e. 5 Mrad = 50 kGy dietary changes and the use of chemical additives. National health authorities took the view that irradiation should be regarded as hazardous until proved safe. This unique situation for a food process presented experimental problems in demonstration of safety which have proved very long term and expensive. Much effort has been provided by the United States through government agencies and the army, whilst in Europe many countries contributed to an international programme of research beginning in 1970 and devoted entirely to this question. Details are given in the papers which follow.

UNITS

The size of radioactive source has up until now been expressed in the very familiar 'curies'. 1 curie represents 3.7×10^{10} disintegrations per second, chosen because this corresponds to 1 gram of radium. Radiation sources used for food irradiation are expected to be of sizes between 1×10^5 and 1×10^6 curies; the latter figure is referred to as a megacurie source. However, the curie is currently being replaced by the 'bequerel'. 1 bequerel is equivalent to 1 disintegration per second; a megacurie source will therefore become 3.7×10^{16} bequerels, a rather extraordinary figure!

The quantity of radiation absorbed by the product being irradiated has for many years been expressed in 'rads'. 1 rad is equivalent to 100 ergs of energy absorbed per gram of product. Again, this unit is changing this year to become 'gray' units. 1 gray represents an absorption of 1 Joule per kilogram of product and is equivalent to 100 rad. A dose of 1 megarad of radiation becomes 10 kilograys.

The changes bring the units in line with the International System of Units (SI). They are summarised as follows:

1 rad (rad) = 0.01 gray (Gy); 1 Gy = 1 Jkg^{-1}
1 curie (Ci) = 3.7×10^{10} bequerels (Bq);
1 Bq = 1 dis sec^{-1}

GENERAL USE IN INDUSTRY

The general potential of irradiation for the treatment of food is seen in Table 1. alongside other processes currently in commercial use in chemical and general biological areas. This brings into context the dose levels required to bring about desired effects. Level of dose is directly related to the size of the radioisotope source required or the power of the electron machine to be installed. In the chemical area requiring high doses to be delivered to high throughputs of wire and cable or fast moving film, the electron machine has been the choice, such machines produce millions of rads in fractions of a second. Because of the limiting electron penetration of foods, machines are most suitable for in-line operation involving the treatment of individual packs no more than a few centimetres in thickness, however, there have been recent advances in the design of such machines and progress in the more efficient production of penetrating X-rays.

Gamma rays are very penetrating and they are particularly suitable in the medical sterilization area where there is a considerable attraction in processing products in their final shipping carton. Cobalt 60 with a half-life of 5.3 years, is the most attractive-radioisotope. It can be produced in large quantities in certain nuclear reactors by bombardment of the inactive cobalt 59 with neutrons for periods usually in excess of 6 months. Canada is the main source of supply with smaller quantities available from France and the UK. Altogether some 100 plants are operating world wide. These plants currently house about 50 million curies between them with a capacity to build up to 100 million and there are several more plants now under construction. Following the commissioning in the UK of the first ever large-scale cobalt 60 plant in 1960, 8 are now in operation. There could be heavy demands to be met if food irradiation is implemented even in limited areas, and no doubt there will be a place for both radiosotope and machine sources.

STIMULATION OF INTEREST IN FOOD IRRADIATION

In December 1979 the Codex Alimentarius Commission of the United Nations adopted a Recommended International General Standard for Irradiated Foods and Recommended International Code of Practice for the Operation of Radiation Facilities for the Treatment of Foods[1], fundamental to which is acceptance that the wholesomeness of irradiated food is not impaired by treatment up to an overall dose of 1 Mrad (10kGy). The Standard is also concerned with the nutritional and microbiological aspects of safety. This recommendation for a general clearance up to a maximum dose level of 1 Mrad comes as a result of the examinations by a UN Expert Committee of the scientific evidence on safety.

TABLE 2

Food applications of particular interest below the upper limit of the recommended dose* of 1.0 Mrad

General Application	Specific Examples	Dose (Mrad)
Decontamination of food ingredients	Various spices Onion powder Dyes Mineral supplements	1.0
Inactivation of Salmonella	Meat and poultry Egg products Shrimps and frog legs Meat and fish meal	0.3 - 1.0
Extended storage of fruit etc.	Strawberries Mangoes Papayas Dates Cocoa beans	0.2 - 0.5
Inhibition of sprouting or growth	Potatoes Onions Garlic Mushrooms	0.01 - 0.3

to convert Mrad to kGy multiply 10 i.e. 1 Mrad = 10 kGy

* With respect to the acceptability of any foods - Report of a Joint FAO/IAEA/WHO Committee (Anon 1981 a).

If legislation is amended to allow food irradiation up to a dose of 1 Mrad (10kGy), the potential for the process is wide, Table 2. Control of micro-organisms features predominantly. A wealth of information is available illustrating quantitative inactivation of microbial populations and the influence of environmental factors.[2] In general, viruses are more resistant than bacterial spores; vegetative organisms, moulds, parasites and insects follow in descending order. Bacetrial populations of spores would be reduced in number by a factor of approximately 10^5 by 1.0 Mrad (10 kGy), whereas Salmonella species would require only 0.5 Mrad (5 kGy) to achieve this level of inactivation. Of immediate commercial interest is the treatment of ingredients. In some instances irradiation could replace ethylene oxide gas for the control of micro-organisms and insects in spice and seasoning manufacture. The quantities involved are within the current capacity of existing radiation plants and the product is expensive enough to tolerate the extra costs. Similarly, Salmonella control is quite practical, although new commercial facilities would be required.

COMMERICAL PROGRESS

Gamma radiation has been used in the UK for the sterilization of laboratory animal diet since 1962, although no food for human consumption has been in general distribution. Other countries also use irradiated diets, bringing the total currently in use to about 1,500 tonnes per annum. The diet is intended for specified pathogen-free and germ-free breeding colonies and useful experience for microbiological control has been gained, as well as evidence of the absence of toxic effect and minimal change of nutritive value. The only exception to the UK prohibitive legislation on human foods is the use of irradiation to treat food intended for patients in hospital who need sterile diets because their natural resistance to infection has been impaired.

The situation is similar in the United States, although a move has been made by the FDA towards accepting irradiation of any foods for general consumption up to a dose of 0.1 Mrad (1 kGy), a factor of 10 below the UN recommendation, which is yet to be considered. The use of doses greater than 0.1 Mrad (1kGy) requires supporting evidence from toxological and mutagenic tests on the food involved. The exception is food which comprises no more than 0.01 per cent of the daily diet when 5 Mrad (50 kGy) allowed, here the FDA no doubt has in mind

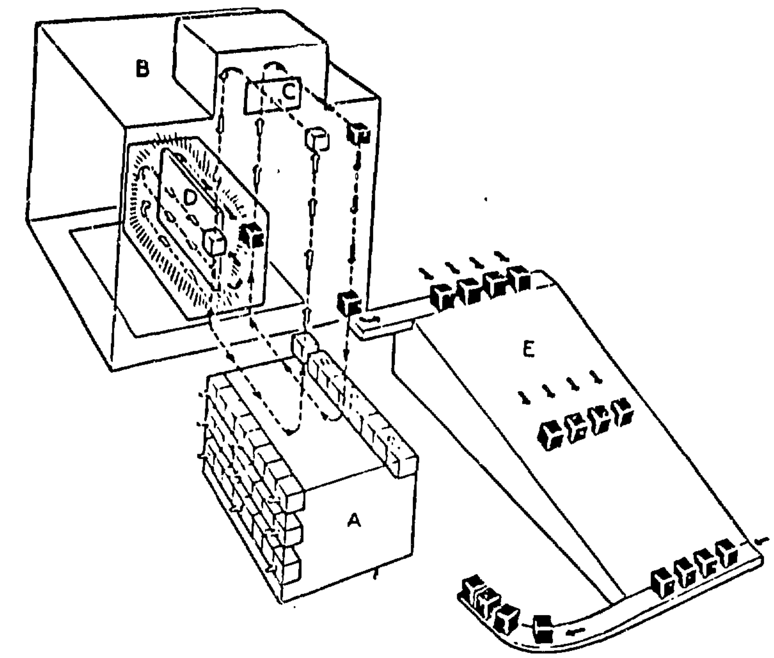

Figure 1 A roller conveyor system carries from storage area A through labryrinth C in concrete shield B. They traverse source D and then emerge at E.

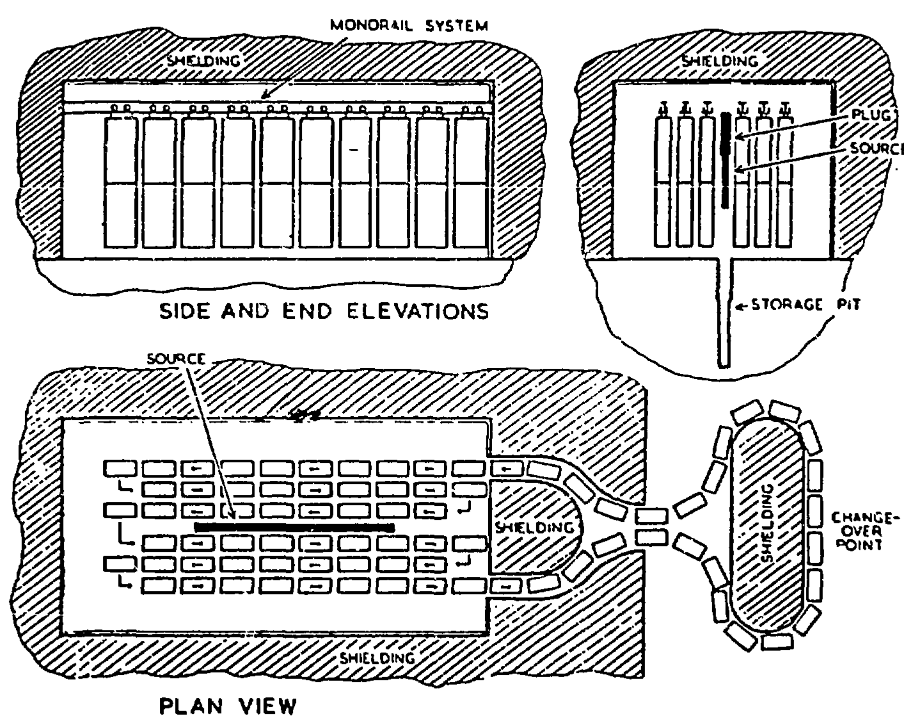

Figure 2 Side and end elevation of a monorail system carrying product through the shielded cell.

spices and other minor ingredients. A dose of 0.1 Mrad (1 kGy) may be in use shortly for the control of Mediterranean fruit fly which seriously infests Californian fruits; irradiation would replace ethylene dibromide treatment.

A number of the applications are already in commercial use in other countries. The first efforts directed to commercial use were made in the early '60s and concentrated on potatoes. Demonstrations were given using mobile irradiators both in Canada and in the USSR.

PLANT DESIGN

The main objectives in designing an irradiation plant are a high utilization of the radiation energy, i.e. high efficiency, and uniform dose throughout the product. Other considerations include a minimum hold-up time in the process and ease of replenishing the radioactive source. To achieve a high efficiency of utilization of the gamma radiation energy it is necessary for the product being treated to occupy a large fraction of the solid angle surrounding the source and to be present in sufficient depth so that the gamma rays are considerably attenuated in passing through it. This latter presents some difficulty when the bulk density of the material being processed is low.

Figures 1 and 2 shows the elements of two designs of 'continuous' plant in which containers of standard size carry product into a suitable concrete cell. One design uses a roller conveyor system and the other a monorail. In either case the containers are pushed by hydraulic or pneumatic rams to and fro across one face of the source and then move across to the other face for similar treatment before emerging. The transfer is so arranged that half the dose is given through one side of the package and half through the opposite side: the minimum dose is received by the plane midway between those two sides, and the ratio of maximum to minimum dose is determined by the thickness and density of the product. The safe store position for the source may be either a deep-water pond 6m deep or a shielded trench into which the source is lowered followed by a shielding plug integral with the source frame. There are many design variables to be taken into account, these are chiefly 1) source height, length and activity, 2) distance between source and nearest target plane, 3) target height and length, 4) target layer thickness and number of layers, 5) container length in direction of travel. The distance between layers, distance between containers within a layer and mass of metal within a target stack should all be minimised. Obviously each plant must be considered individually for the purpose intended.

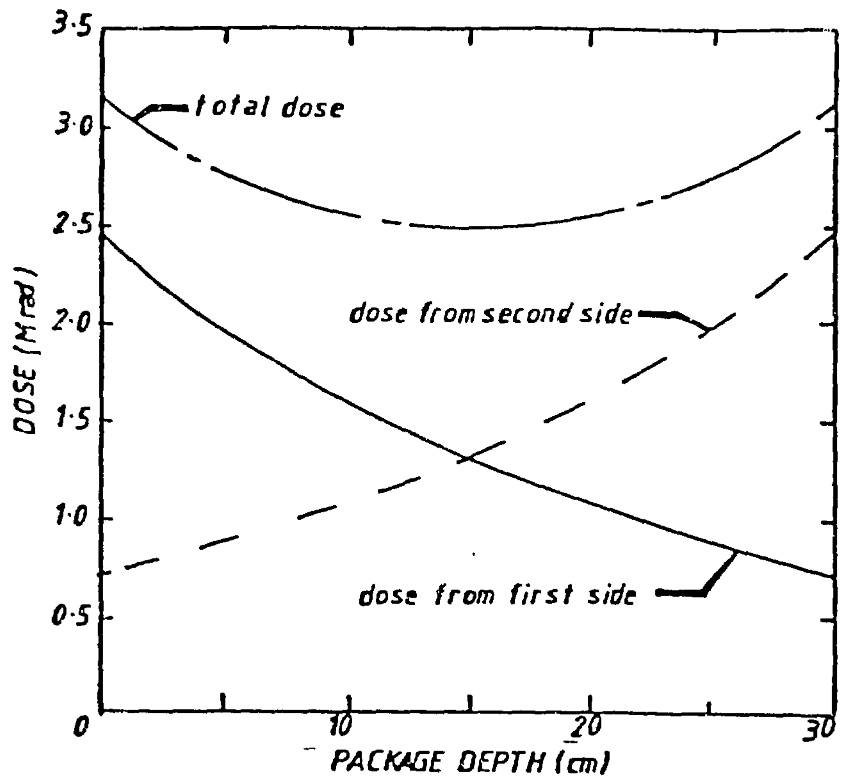

Figure 3 Penetration of target density 0.3g/cm^3 by cobalt-60 gamma rays.

The distribution of dose throughout a product will depend upon its bulk density and thickness. A product which occupies the whole of an irradiation container might present 45 cm thickness to the source and is irradiated equally from opposite sides. If the target is medical plastic disposables of typical density 0.20, the overdose ratio is approximately 1.2. The same overdose ratio is achieved for density 0.3 when the target thickness is 30 cm as shown in Figure 3. The ratio can be reduced by manipulation of the target itself halfway through the process. This technique is often used with high density material such as plastic sheet or spools of wire. For example, an 18 cm target of mean density 1.5 can be irradiated to achieve an overdose ratio of approximately 1.3.

PROCESS CONTROL

A high standard of control is demanded in relation to the use of a facility for the radiation sterilization of medical supplies. Incoming and outgoing product is physically separated and detailed records of consignments maintained. Table 3 summarises the various areas which are involved. Particular emphasis is given to dosimetry.

Film system, usually clear or red polymethyl methacrylate are widely used to monitor the radiation dose in routine plant operation and at commissioning. At the latter time the pattern of dose distribution within standard packages and the relationship between dose and target density are established by experimental runs. In routine operations dosimeters are regularly inserted throughout a product being placed in areas where the dose is expected to be at a minimum. Red Perspex dosimeters as developed by Whittaker (3) complete with calibration curve are purchased in the UK from Harwell or clear Perspex HX (4) from the UK Panel on Gamma and Electron Irradiation, and from similar organizations in other countries. Records of readings are carefully maintained for inspection.

For convenience of the plant operator and the recipient of the products, small adhesive radiation indicator labels are affixed to the outside of each item of product e.g. carton or spack. The label changes from yellow to red during irradiation and helps to ensure against confusing irradiated with unirradiated product. The label is based on PVC impregnated with an acid-sensitive dye, and was formulated for the purpose by Farrell and Vale (5); a similar label with changes from green to brown has been developed in the Netherlands. These labels are by no means quantitative and fulfil a 'go'or'no go' function.

TABLE 3

Area of Process Control

Source	(Curie strength (Specific activity (Array (Decay Rate
Conveyor	(Position (Speed or dwell (Interlock with source (Movement record chart
Product	(Separation - pre and post irradiation (Density and thickness (Dosimetry (Labelling
Documentation	(Plant log (Chart records (Product log (Dosimetry records (Certificate of Irradiation

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