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Irradiation of bulbs and tuber crops

A compilation of technical data for its authorization and control

International Consultative Group on Food Irradiation established under the aegis of FAO, IAEA, WHO

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FOREWORD

The International Consultative Group on Food Irradiation (ICGFI) was established on 9 May 1984 under the aegis of FAO, IAEA and WHO. ICGFI is composed of experts and other representatives designated by governments which have accepted the terms of the "Declaration" establishing ICGFI and have pledged to make voluntary contributions, in cash or in kind, to carry out the activities of ICGFI.

The functions of ICGFI are as follows:

(a) To evaluate global developments in the field of food irradiation;
(b) To provide a focal point of advice on the application of food irradiation to Member States and the Organizations; and
(c) To furnish information as required, through the Organizations, to the Joint FAO/IAEA/WHO Expert Committee on the Wholesomeness of Irradiated Food, and to the Codex Alimentarius Commission.

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Argentina, Australia, Bangladesh, Belgium, Brazil, Bulgaria, Canada, Chile, Costa Rica, Côte d'Ivoire, Croatia, Cuba, Czech Republic, Ecuador, Egypt, France, Germany, Ghana, Greece, Hungary, India, Indonesia, Iraq, Israel, Italy, Malaysia, Mexico, Morocco, Netherlands, New Zealand, Pakistan, People's Republic of China, Peru, Philippines, Poland, Portugal, Republic of Korea, South Africa, Syrian Arab Republic, Thailand, Turkey, Ukraine, United Kingdom, United States of America, Viet Nam and Yugoslavia.

This publication contains a compilation of available scientific and technical data on the irradiation of bulbs and tuber crops. It is intended to assist governments in considering the authorization of this particular application of radiation processing of food and in ensuring its control in the facility and the control of irradiated food products moving in trade. The compilation was prepared in response to the requirement of the Codex General Standard for Irradiated Foods and associated Code that radiation treatment of food be justified on the basis of a technological need or of a need to improve the hygienic quality of the food. It was also in response to the recommendations of the FAO/IAEA/WHO/ITC-UNCTAD/GATT International Conference on the Acceptance, Control of and Trade in Irradiated Food (Geneva, 1989) concerning the need for regulatory control of radiation processing of food.

It is hoped that the information contained in this publication will assist governments in considering requests for the approval of radiation treatment of bulbs and tubers, or requests for authorization to import such irradiated products.

It is suggested that the various guidelines, codes and other documents adopted by ICGFI or prepared under ICGFI's auspices be also consulted (see Bibliography).

This compilation of data was prepared by P. Thomas, Food Technology Division, Bhabha Atomic Research Centre, India, and reviewed by J. Farkas (Hungary), T. Hayashi (Japan), M. Lapidot (Israel) and M. Matin (Bangladesh). The IAEA staff member responsible for this work was P. Loaharanu of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

Bulb and tuber crops are important food vegetables cultivated and consumed in most areas of the world. Onions (*Allium cepa* L. var. *cepa*), shallots (*A. cepa* L. var. *ascalonicum*), and garlic (*A. sativum* L.) constitute the major bulb crops whereas potatoes (*Solanum tuberosum* L.) and yams (*Dioscorea* spp.) form the economically important tuber crops.

The onion is universally important and perhaps one of the world's oldest cultivated vegetables which is widely used for culinary purposes to improve the gastronomic properties of nearly every food except desserts. Apart from their characteristic flavor, taste and pungency, onions possess remarkable medicinal powers and antifungal and antibacterial properties. Garlic and shallots, the other two bulb crops belonging to the onion family, are neither cultivated nor used for culinary purposes as extensively as onions. However, garlic is believed to possess remarkable medicinal powers and is of economic importance to many countries. Garlic juice and its volatile components are reported to possess strongly bactericidal and fungicidal properties.

The potato, the most important tuber crop, grown largely as a carbohydrate staple and also for industrial purposes, is often thought to be a crop of the industrialized nations of the temperate zones. However, in recent years there has been a steady increase in the cultivation of potatoes in non-traditional environments, in the warm, generally drier areas as well as the warm, humid zones in the tropics and sub-tropics. Developing countries in Africa, Asia and Latin America now produce a third of the world's potatoes and the crop is increasingly utilized in the food system of these countries. Yams are a staple carbohydrate food crop in the yam zone of West Africa and are also of importance in South East Asia, countries of the Pacific and Caribbean.

In many growing regions of bulb and tuber crops production throughout the year is not possible and therefore postharvest storage technologies are required to provide consumers with stable supplies of these commodities in both fresh as well as processed forms. Also, bulb and tuber crops are important items of international trade and require to be stored and transported while maintaining the best possible quality.

Because of the high water content and the difficulty of storing, processing, and transportation, postharvest losses in bulb and tuber crops are potentially very high. The various factors contributing to both qualitative and quantitative deterioration of these commodities could be broadly grouped under four categories such as physical, physiological, microbiological and entomological. Pre-harvest cultural practices, growing conditions, harvest maturity, harvesting and handling methods, proper curing of the harvested produce and postharvest storage conditions all can influence the type and extent of losses occurring in stored bulb and tuber crops.

The objective of treating harvested bulbs and tubers with low dose ionizing radiation is to prevent the physiological processes leading to sprouting during extended storage. Losses on account of other factors may continue to occur in storage and need to be controlled by appropriate storage management procedures as discussed in later sections of this report.

This technical compilation was prepared under the sponsorship of ICGFI, and it is intended to provide a comprehensive account of the available scientific and technical data on irradiation of bulb and tuber crops for the control of sprouting. Three major reviews have been published on the radiation preservation of bulb and tuber crops (Matsuyama and Umeda

1983; Thomas 1984, 1986). Most of the published work refers to treatment with gamma rays using either cobalt-60 (^{60}Co) or cesium-137 (^{137}Cs) isotopic sources.

2. JUSTIFICATION FOR RADIATION PROCESSING

2.1. SIGNIFICANCE OF SPROUTING IN STORAGE

Of the various physiological factors which affect storage of bulbs and tubers, sprouting is the most obvious manifestation of deterioration. Sprouting does not start immediately after harvest and there is usually a time lag, the dormant period, which may last several weeks before growth resumes. The dormancy period depends on variety, climatic conditions during growth, harvest maturity, mechanical damage, microbial infections, and the storage environment particularly the temperature.

In potatoes, dormancy breaks more readily when tubers are kept at temperatures above 5°C, are damaged, or are infected by disease (Eddowes, 1978). In countries with a temperate climate, potatoes harvested in the autumn remain dormant until early in the following spring when they start to sprout; in countries where the ambient temperatures are higher, dormancy break and sprout growth occurs much earlier.

At temperatures of 5° to 15°C, especially at the latter, the dormancy of onions, shallots, and garlic is shortened and can result in a more vigorous sprout growth under high humidity conditions (Abdalla and Mann, 1963; Karmarkar and Joshi, 1941; Mann and David, 1956; Sinnadurai and Amuti, 1971, Thomas *et al.*, 1975).

In yams, metabolic losses may account for one-third of the total weight losses of sound tubers during storage (Coursey, 1967). Sprouting contributes immensely to metabolic losses and this is one of the most important causes of deterioration in stored yams (Adesuyi and Mackenzie, 1973). Sprouting could occur in 100% of the yams after 4 months storage under ambient conditions (Coursey, 1961).

Sprouting of tuber and bulb crops during storage can be detrimental to their nutritive value and marketability. The undesirable changes that occur during sprouting include: loss of marketable weight, loss of nutritional value, softening, shrivelling due to enhanced rate of water evaporation from the sprouts, loss of processing qualities, temperature build up associated with respiration rate, susceptibility to bruising and enzymatic discoloration and problems with sorting and grading of sprouted materials (Eddowes, 1978; Thomas, 1984, 1986). Peeling losses are greater in sprouted potatoes, and the sprouts contain increased levels of the toxic alkaloid solanin.

2.2. ALTERNATE METHODS FOR CONTROL OF SPROUTING

2.2.1. Low temperature storage

Bulb crops for fresh usage can be stored for sufficiently long durations at a temperature of 0°C with a relative humidity (RH) of 65 to 70%. Control of temperature and humidity of the storage air are essential for success in the storage of onions, shallots and garlic as any deviations above these levels can lead to early sprouting and rooting. Subfreezing storage of onions is also practiced as a useful alternative when chemical sprout inhibitors cannot be used. In Europe, storage below the freezing point has been recommended and, when this method is used, the onions are quickly cooled to 0.6° to 1.1°C; when the room is filled, the temperature is lowered further to -1.1° to -2.2°C. Before the onions are taken out of storage, they are thawed over a period of 1 to 2 weeks with the air about 4.4°C (Ryall and Lipton, 1972). Similarly, storage at about 0°C and RH 80 to 85% can minimize the losses due to sprouting, rooting, desiccation, and microbial spoilage in garlic and the bulbs can be held for 8 to 9 months in good condition (Ryall and Lipton, 1972).

In most potato varieties sprout growth ceases at temperatures below 4°C. A temperature of 4° to 5°C and a relative humidity of 92 to 95% are considered to be ideal for prolonged potato storage (van der Zaag, 1973). However, the reducing sugar content of potatoes increases gradually at this temperature and the reducing sugars are the chief cause of undesirable brown discoloration in processed products like chips and crisps. Reconditioning of cold stored tubers at 15° to 20°C before further processing into chips can reduce the sugar content to acceptable levels but in tubers having high sugar content reconditioning may not bring down its level to that required for processing.

Due to its extreme sensitivity to chilling or low-temperature injury, it is not feasible to store yams for longer durations under refrigeration. Yams, are susceptible to physiological breakdown when stored at about 12°C or lower (Coursey, 1968; Noon, 1978; Noon and Colhoun, 1981). A storage temperature of about 16°C and about 70% RH are considered near optimum conditions for the long-term storage of cured tubers (Noon, 1978); yams of *D. alata* can be stored well without sprouting at 15°C for 18 weeks (Olurunda *et al.*, 1974).

2.2.2. Chemicals

At present the extended storage of onions and garlic in some countries is achieved by preharvest spraying with maleic hydrazide (MH, 1,2-dihydropyridazine-3-6-dione), a chemical which prolongs dormancy via its effect on nucleic acid metabolism and cell division rather than on endogenous hormonal control (Del Rivero and Cornejo, 1971; Thomas,T.H. 1981). However, this chemical does not have universal clearance. The effectiveness of maleic hydrazide depends on its translocation into the inner meristem or growth points where it could act upon, and thereby inhibit sprouting. The chemical is applied to the crop, usually 2 to 3 weeks before harvest when enough green foliage is present to facilitate its absorption and translocation (Del Rivero and Cornejo, 1971; Isenberg, 1956; Wittwer *et al.*, 1950). Preharvest spraying with ethephon (2-chloroethyl phosphonic acid) also keeps the onion bulbs dormant, for fairly long periods (Pedeliski, 1973). MH application does not result in good sprout control when storage is at higher ambient temperatures (Thomas, 1984). Postharvest application of isopropyl-N-phenylcarbamate (IPC) and the methyl ester of natphthalene acetic acid (MENA) in the vapor form, which are commercially used for sprout inhibition of potatoes, are not effective for bulb crops (Sawyer and Dallyn, 1959), possibly due to their poor penetration and translocation into the inner meristem.

A number of chemical inhibitors of cell division such as Cloropropham [CIPC, isopropyl-N-(3-chlorophenyl)carbamate], Propham [IPC, isopropyl-N-phenyl carbamate], Tecnazene [TCNB, Tetrachloro nitrobenzene], MENA, MH-40 or MH-30, and Nonyl alcohol (Nonanol) are extensively used to inhibit sprouting in potatoes. In general, chemical sprout inhibitors have proved effective to permit long-term storage of potatoes stored at about 7° to 10°C (Booth and Proctor, 1972; Smith, 1977). Among the various chemicals, the most widely used are preharvest sprays of MH-40 and MH-30 and postharvest application of CIPC or a mixture of IPC and CIPC. The effectiveness of MH is dependent on the time of application as well as storage temperature. Sprouting may occur under relatively high storage temperatures and heavy MH applications are required to reduce losses from sprouting (Patterson *et al.*, 1952; Sawyer, 1962). CIPC and other chemicals are applied to potatoes in bulk storage through circulation in the air or by dusting over the tubers. In general, the quality of potatoes treated with chemical sprout inhibitors remain satisfactory provided that good storage practices are also used.

The effectiveness of chemical sprout inhibitors on yams vary from species to species. Preharvest sprays of MH reduced weight loss during storage of *D. alata* for 14 weeks but had no effect on *D. esculenta* (Hayward and Walker, 1961). Application of CIPC or IPC did not prevent sprouting in *D. alata* stored at 20°C but at 25°C it prevented further sprouting of desprouted tubers (Olorunda *et al.*, 1974). In general, CIPC, MH, MENA and TCNB were found ineffective in inhibiting sprouting in tubers of *D. alata* and *D. rotundata* during normal storage (Adesuyi and Mackenzie, 1973; Olrounda *et al.*, 1974).

Most of the chemical sprout suppressants, except TCNB, inhibit the development of wound periderm in potato tubers and may lead to an increase in the incidence of microbial rot in storage if applied to freshly harvested potatoes which have not been well cured. Moreover, use of chemical sprout inhibitors gives rise to the presence of residues of the chemical in or on the tubers and bulbs and there is a growing concern about the safety of these residues.

2.2.3. Storage at high temperatures

Dormancy of onions, shallots and garlic is prolonged at storage temperatures above 25°C (Abdalla and Mann, 1963; Karmarkar and Joshi, 1941; Thomas *et al.*, 1975). In many tropical countries, storage of bulb crops is usually at ambient temperatures because of the expense of refrigeration. While these temperatures yield satisfactory onions for the fresh market, long-term storage under such conditions can cause excessive microbial spoilage and also desiccation and shrinkage of the bulbs particularly in garlic and shallots.

2.3. RADIATION TREATMENT FOR SPROUT INHIBITION AND SHELF-LIFE IMPROVEMENT

Sprout inhibition in bulb and tuber crops at low dose levels is one of the most promising and extensively studied applications of ionizing radiation in food preservation. As early as 1936, it was shown that sprouting in vegetables can be inhibited with X-rays (Metlitsky, 1936) and a later study in 1950 reported that a small dose of 0.045 kGy of X-rays markedly inhibited the germination of seed potatoes (Sparrow and Christensen, 1950). Since then, with the availability of radiation facilities utilizing ^{60}Co and ^{137}Cs isotopic sources, extensive studies have been undertaken in many countries to establish the optimal technological conditions for the irradiation treatment of different cultivars of bulb and tuber crops grown under different agro-climatic conditions. A summary of these studies on bulb and tubers are given in Annex 1 and 2 respectively, which shows the varieties/cultivars and radiation doses used, optimal dose and dose range, time interval between harvest and irradiation treatment, storage temperature and relative humidity, and length of storage.

In onions, although the differences in cultivars can influence the results to some extent, the effectiveness of irradiation for satisfactory sprout control is very much dependent on the habitat, preharvest growing conditions, cropping season, state of dormancy of the onion bulb at the time of irradiation, the radiation doses employed, and post-irradiation storage environment particularly the temperature and humidity (Thomas, 1986). Most of the results on bulb crops seem to agree that for maximum sprout inhibition irradiation should be carried out soon after harvest and curing, when they are in the dormant period, to doses in the range of 0.02 to 0.12 kGy. This is not the case with potatoes in which regardless of cultivar and post-irradiation storage temperature a dose of 0.1 kGy inhibits sprouting irreversibly (Thomas, 1984). In general, best results are obtained when good quality tubers harvested with minimal injuries and cured sufficiently to heal the bruises and wounds, are irradiated to a dose of 0.07 to 0.1 kGy. It is also important, that, if possible, potatoes should be cured, irradiated and stored all in the same container to minimize handling damage during and following irradiation as wound periderm formation is impaired after irradiation (See Section 2.5.4.). Although the storage temperature is governed more by the intended end use of the potatoes than by any other criterion, the optimal temperature for storage of irradiated potatoes seems to be about 7.5° to 10°C, a temperature at which rot development is kept to a minimum. Potatoes meant for fresh consumption as table stock can be stored at relatively low temperatures (2° to 5°C), while higher storage temperatures of 7.5° to 10°C are suitable for tubers intended for processing. Long-term storage of irradiated potatoes at the higher ambient temperatures prevailing under tropical environments is out of the question, since spoilage particularly due to bacterial soft rot takes a heavy toll of the produce (Thomas *et al.*, 1978a, 1978b).

The various factors influencing the sprout inhibition of bulb and tuber crops by ionizing radiation are discussed in more detail in the ensuing Sections.

2.3.1. Time interval between harvest and irradiation

Bulbs: Many studies have shown that irradiation at appropriate low dose levels during the dormancy period is most effective for sprout inhibition. The length of the dormancy period may vary among cultivars and cropping season and is also dependent on the storage temperature following harvest. Even during the dormancy period, some growth of the inner buds takes place. In general the effectiveness of sprout control decreases with the increasing interval between harvest and irradiation.

Studies carried out in different parts of the world with several onion cultivars grown under varying agro-climatic conditions have demonstrated that doses in the range of 0.02 to 0.09 kGy assures adequate control of sprouting if irradiated shortly after harvest, preferably within 2 to 4 weeks (Chachin and Ogata, 1971; Diehl, 1977; Grunewald, 1977, 1978; Grunewald *et al.*, 1978; Meshitsuka, *et al.*, 1962; Mullins and Burr, 1961; Park *et al.*, 1972; Skou, 1971; Takano *et al.*, 1974c; Thomas, 1986; Thomas *et al.*, 1975, Umeda *et al.*, 1970; Zehnder, 1984). In certain cultivars good sprout control has been obtained even when irradiation was carried out between 1 and 3 months of harvest (Curzio and Croci, 1983; Mahmoud *et al.*, 1978; Ojima *et al.*, 1963; Park *et al.*, 1972; Takano *et al.*, 1972a, 1974c; Umeda *et al.*, 1970; Matin *et al.*, 1985). Dormancy period of onions can be extended by storage at 0°C (Chachin and Ogata, 1971) or 3° to 5°C (Takano *et al.*, 1974a) and satisfactory sprout control, in such low temperature stored onions can be obtained during subsequent storage by irradiation to doses in the range of 0.03 to 0.15 kGy. Extended dormancy in onions is also observed when storage is at 30°C or above as in the tropics and irradiation during this period has been found to control sprouting occurring at the later part of storage under ambient conditions (Thomas, 1993).

The influence of delay between harvest and irradiation is not well documented in shallots and garlic. However, the comparatively few studies on garlic have shown that doses in the range of 0.02 to 0.06 kGy if applied shortly after harvest, when the bulbs are in the dormant period, can result in 100% inhibition of sprouting (Brunelet and Vidal, 1960; Curzio and Croci, 1983; Curzio *et al.*, 1983, 1986a; Habibunisa *et al.*, 1971; Kwon *et al.*, 1985; Mathur, 1963a; Messiaen and Leroy, 1969; Watanabe and Tozaki, 1967), whereas doses of 0.10 to 0.15 kGy may be required if they are irradiated at later stages (Anon., 1968; El-Oksh *et al.*, 1971; Lustre *et al.*, 1981; Singson *et al.*, 1978).

Tubers: Sprout inhibition in potatoes is most pronounced if irradiated immediately after harvest when tubers are in their dormancy period. As time after harvest increases larger doses are required to prevent sprouting (Jaarma, 1969b; Mathur, 1963b; Metlitsky *et al.*, 1968). On the other hand, some studies indicate that the effectiveness of irradiation for sprout control is not affected by delay between harvesting and irradiation, if treated during the dormancy period (Hendel and Burr, 1961).

2.3.2. Radiation dose

Bulbs: It is well established that the optimal dose for good sprout control in bulb crops is in the range of 0.02 to 0.09 kGy if treatment is carried out shortly after harvest during the dormancy period. Higher doses of 0.12 to 0.25 kGy and more can cause a transient stimulation of sprouting in onions, although the growth of sprouts is not sustained and they wither off subsequently (Skou, 1971; Thomas, 1986). Higher doses may also induce increased rotting and other undesirable effects disadvantageous for commercial irradiation (Matsuyama and Umeda, 1983).

Tubers: The minimum dose required for effective sprout control in tubers is higher than that for bulbs (Matsuyama and Umeda, 1983; Thomas, 1984). In potatoes doses between 0.05 and 0.15 kGy, preferably a dose range from 0.07 to 0.15 kGy is sufficient to inhibit sprouting regardless of cultivar, time of irradiation and post irradiation storage temperature (Burton and Hannan, 1957; Hendel and Burr, 1961; Metlitsky *et al.*, 1968; Rubin *et al.*, 1959; 1961; Siddiqui *et al.*, 1973; Hossain *et al.*, 1985; Thomas, 1984). Sprouts already present wither off during storage and development of new sprouts is prevented. Doses exceeding 0.15 to 0.20 kGy can result in increased darkening or browning, decreased wound healing ability, increased storage rot, spoilage, sweetening, decreases in vitamin content and changes in chemical composition which do not disappear during subsequent storage (Brownell *et al.*, 1957b; Cloutier *et al.*, 1959; Gustafson *et al.*, 1957; Matsuyama and Umeda, 1983; Metlitsky *et al.*, 1967; Schreiber and Highlands, 1958a; Sparrow and Christensen, 1954; Waggoner, 1955).

In yam tubers, in which sprouting had not commenced, the minimum effective dose for inhibition of sprouting was 0.075 kGy (Adesuyi and Mackenzie, 1973; Rivera *et al.*, 1974) whereas a dose of 0.2 kGy was necessary to inhibit sprouting in tubers that already had sprouted at the time of irradiation (Adesuyi and Mackenzie, 1973). To ensure acceptability, palatability, and complete sprout inhibition without adverse physiological effects, a dose of 0.125 kGy proved suitable for 8 cultivars when irradiated as soon as harvest damage was healed (Adesuyi, 1976, 1978).

2.3.3. Influence of cultivar

In bulbs, the influence of cultivar sensitivity to irradiation is not well documented while in potatoes the minimum dose requirement for effective sprout inhibition is known to differ among cultivars (Burton and de Jong, 1959; Burton and Hannan, 1957; Hansen and Gurnewald, 1964; Mathur, 1963b; Mckinney, 1971; Metlitsky *et al.*, 1957; Mikaelsen *et al.*, 1958; Park *et al.*, 1967; Sawyer and Dallyn, 1955). However, regardless of cultivar differences, a 0.07 to 0.10 kGy dose should inhibit sprouting under any commercial practical storage conditions (Freund, 1965) ranging from 10°C to tropical ambient temperatures of 30° to 37°C (Thomas, 1984; Thomas *et al.*, 1978 a,b).

Similarly, different yam cultivars exhibit variations in the effective dose for sprout inhibition, ranging between 0.075 and 0.125 kGy, although a dose of 0.125 kGy provided good sprout control in all cultivars (Adesuyi, 1976, 1978).

2.3.4. Dose rate effect

A few studies have shown a dose rate effect on sprout inhibition in onions (Furata *et al.*, 1978; Hori and Kawasaki, 1965; Ogata and Chachin, 1972) and potatoes (Jaarma, 1969b; Kruschev *et al.*, 1964; Mathur, 1963b; Metlitsky *et al.*, 1968; Scheid and Heilinger, 1968), a dose delivered at a high dose rate being more effective than the same dose delivered at a low rate. Not withstanding these results, it needs to be emphasized that the dose rate effect may not be of much practical significance in industrial scale irradiation facilities where a fairly adequate dose rate is required to obtain reasonable product throughput when large product volumes are to be processed within a short period of time.

2.4. IRRADIATION EFFECT ON CHEMICAL CONSTITUENTS

2.4.1. Carbohydrates

Bulbs: Although normally onions, shallots and garlic are not consumed for their nutritional value, several investigators have studied the changes occurring in sugars following irradiation for sprout inhibition because of its effect on sensory properties. In general no significant effect of irradiation on the sugar content of onions has been observed (Dallyn and Sawyer, 1954; Diehl, 1977; Grunewald, 1978; Guma and Rivetti, 1970; Guo *et al.*, 1981; Metlitsky *et al.*, 1967; Salems, 1974; Shalinova and Vashchinskaya, 1967; Tada and Shiroishi, 1969; Thomas *et al.*, 1986).

In certain cultivars grown in the USSR the carbohydrate composition of onions irradiated with a dose up to 0.01 kGy varied little, and 2 months after irradiation the content of reducing and nonreducing sugars were 3.05 and 5% respectively as against 2.15 and 5% in the nonirradiated samples (Metlitsky *et al.*, 1967). Similarly no significant changes in the sugar content of "Sapporo yellow" onions irradiated either soon after harvest or after 1 month storage at room temperature was observed during storage at room temperature or at 1°C (Tada and Shiroishi, 1969). Gas chromatography of silylated extracts showed no changes in levels of glucose, fructose or malic acid in four onion cultivars grown in Germany when irradiated with 10 MeV electrons at doses of 0.05 or 0.10 kGy and stored at 10°C or 20°C. Sucrose level was about 2.2% of fresh weight at the beginning of storage period and declined to about 1.5% in irradiated as well as unirradiated bulbs (Diehl, 1977; Grunewald, 1978).

In the onion cultivars Grano, Egyptian, and Riverside grown in Israel, the content of reducing sugars, total sugars, total soluble solids, and dry matter was essentially the same in 0.07 kGy irradiated and control samples, 1 day after irradiation and during 5-months storage at ambient temperature (Molco and Padova, 1969). Similarly, doses of 0.05 to 0.5 kGy caused no appreciable effects on the total free sugar content (sucrose, glucose, and fructose) in onion bulbs of 11 cultivars produced in different locations in Japan, though sucrose content seemed to be slightly increased by irradiation (Nishibori and Namiki, 1982).

During sprouting considerable increases in reducing sugar were recorded in nonirradiated onion bulbs while the changes were less in irradiated bulbs (Mahmoud *et al.*, 1978).

Tubers: Contradictory results have been reported in the literature on the effect of irradiation on sugar content of potatoes during storage. These differences could be due to the variation in the varieties, time of irradiation, and storage temperature. Two types of increases in the sugar level have been observed: (1) a temporary rise in both reducing and non-reducing sugars which often returns to the normal level during further storage, and (2) an increase in sugars on prolonged storage or senescent sweetening. Increased sugar content in potatoes can render them unsuitable for processing into chips, crisps, or french fries.

In Danish potato cultivars irradiated between 0.04 and 0.16 kGy, sucrose and glucose increased while fructose decreased. These changes, were reversible and disappeared after storage for some months at 5°C (Jaarma, 1958). In cultivars grown in the U.K. a marked increase in sucrose was observed in tubers irradiated with 0.1 kGy and stored at 10°C. Maximum content was reached 5 days after irradiation, after which it decreased; 26 days after irradiation it was about the same as in nonirradiated tubers (Burton *et al.*, 1959). Pre-storage of potatoes for 4 weeks at 2° to 15.5°C before irradiation to 0.1 kGy influenced the sugar content during post-irradiation storage (Burton, 1975). Pre-irradiation storage of tubers showed a marked temporary increase in sucrose, reaching a maximum after 3 to 7 days before decreasing to a level which was still higher than that of nonirradiated tubers. Tubers stored at 2°C showed an immediate decrease in sucrose after irradiation, followed within 3 days by a rise to values not significantly different from the controls. In the Japanese cultivar Deijima stored at 20°C the sucrose content of tubers irradiated with a dose of 2 kGy increased for 2 weeks after irradiation from 0.13 to 2.4% and then remained at that level, while that of the tubers irradiated at 0.15 kGy increased for 1 week and then decreased to the level of controls (Hayashi and Kawashima, 1983a). The sustained high level of sucrose reported in 2 kGy treated tubers has no practical importance since the dose employed is almost 20 times more than that required for sprout control.

Storage temperature influences the rise in the content of sucrose and reducing sugars in irradiated potatoes. Tubers stored at 1.5°C for 7 months recorded higher sugar levels than nonirradiated tubers, while at a higher temperature irradiated tubers had less sugars than the corresponding control samples (Metlitsky *et al.*, 1957). Similarly, increased reducing sugar levels were recorded in 0.1 and 0.25 kGy treated tubers stored at 0° to 4°C for one month as compared to those stored at 25°C.

There have also been reports that irradiation could cause a reduction in the content of reducing sugars soon after treatment (Filep and Kaposztassy, 1971; Pedersen, 1956; Rubin and Metlitsky, 1958; Sereno *et al.*, 1959).

A comparison of sugar changes in 0.1 kGy treated potatoes during storage at 14°C and in nonirradiated potatoes at 4° to 5°C for 6 months showed a 50% lower content of reducing and total sugars as well as 15% greater starch content in the irradiated tubers than in controls (Eisenberg *et al.*, 1971). A similar study with several Indian potato cultivars revealed that sugar accumulation in nonirradiated tubers stored at 2° to 4°C progressed at a faster rate than in irradiated tubers at 15°C during a 6 month storage period (Joshi *et al.*, 1990. The pattern of sugar accumulation was rather similar in both irradiated and nonirradiated potatoes during storage at either 15°C or 27° to 32°C. Reducing sugar changes in several Indian potato cultivars, which were sprout inhibited by either chloroisopropyl n-phenyl carbamate (CIPC) or 0.1 kGy irradiation were found to follow the same trend, tubers stored at 10°C showing increased levels compared to those stored at 15° or 20°C (Shirsat *et al.*, 1994).

In yam tubers of *D. rotundata* starch levels were almost identical in control and 0.15 kGy treated tubers after a storage period of 5 months under normal conditions (25° to 37°C; RH 50 to 85%); a decrease in starch level was recorded in tubers irradiated to 0.1 and 0.125 kGy but those exposed to 0.025, 0.05 and 0.075 kGy had higher starch content than 0.1 and 0.125 kGy treated samples (Adesuyi and Mackenzie, 1973).

2.4.2. Ascorbic acid

Bulbs: Although onions are not consumed for its vitamin C, several studies have been undertaken on the changes in vitamin C content following irradiation and during storage. The vitamin C content in 3 onion cultivars grown in Israel following irradiation to 0.07 kGy and 5 months storage at ambient temperature was essentially the same as in nonirradiated controls (Molco and Padova, 1969). An increase in ascorbic acid content with increasing dose from 0.03 to 0.18 kGy was observed in one study (Nandpuri *et al.*, 1969) while another study reported a 18% reduction of ascorbic acid following 0.08 kGy irradiation (Salems, 1974). Little difference in vitamin C content between 0.06 kGy treated and untreated onions was found during 9 months storage (Derid and Shalinova, 1967) and the loss in ascorbic acid at doses of 0.02 to 0.06 kGy was accompanied by increased levels of dehydro-ascorbic acid which is also biologically active (Ghod *et al.*, 1976).

In a study with onion cultivars of Hungary, no significant differences in the vitamin C content of irradiated and nonirradiated samples were observed during a 10-month storage period and the vitamin C content of irradiated samples seemed to be independent of the time of irradiation after harvest (Mahmoud *et al.*, 1978). The vitamin C content of the inner buds tended to be less than in the flesh, and at the end of 10 months the less developed external sprouts, if any, present in the irradiated bulbs contained much less vitamin C (100 to 200 mg % on dry weight basis) than the well developed sprouts (1200 mg %) in the unirradiated bulbs.

A drastic reduction in vitamin C content of onions was observed immediately after irradiation at 0.1 to 0.5 kGy, however the decrease in vitamin C during the remaining period of 8 months storage was much lower in irradiated than in control onions (Guo *et al.*, 1981).

The results of most of the studies reported above indicate that irradiation does not adversely affect the vitamin C in onion and any changes occurring soon after irradiation are restored to the levels in nonirradiated samples during storage.

Tubers: Since potatoes are a good source of vitamin C, several workers have studied the stability of this vitamin in tubers irradiated for sprout inhibition purposes. Most of the studies indicate vitamin C is stable during and after irradiation. Although a reduction in vitamin C level not exceeding 15% has been observed during the early storage period following irradiation at sprout inhibition doses, the amount of the vitamin after prolonged storage is reported to be comparable or even greater than that of nonirradiated tubers stored under identical conditions (Joshi *et al.*, 1990; Matsuyama and Umeda 1983; Mikaelson and Roer, 1956; Ogata *et al.*, 1959a; Panalkas and Pelletier, 1960; Schwimmer *et al.*, 1958, WHO, 1970, 1977).

An immediate oxidation of vitamin C was observed following irradiation at 0.1 kGy but the difference in content between irradiated and nonirradiated tubers disappeared on prolonged storage (Salkova, 1957) and after 8 months storage the vitamin C contents were 7.0 mg % for unirradiated and 6.8 mg % for irradiated tubers (Rubin and Metlitsky, 1958). The initial loss of ascorbic acid was followed by increases with the onset of warmer temperatures during storage of tubers (Schreiber and Highlands, 1958b). Irradiation with 0.07 to 1.0 kGy 2 weeks after harvest had no effect on vitamin C (Metlitsky *et al.*, 1968). On the other hand, in one study no immediate change in vitamin C content was observed after exposure to 0.1 to 1.0 kGy, but after 1 week the levels decreased in proportion to increasing dose (Gounelle *et al.*, 1968).

In five South African potato cultivars no detrimental effect on ascorbic acid was observed after exposure up to 0.15 kGy, during 16 weeks of storage (Winchester and Visser, 1975).

Similar observations were made by many others (Baraldi *et al.*, 1971a; Boffi *et al.*, 1969, Krylova, 1957; Patzold and Kolb, 1957; Patzold and Weiss, 1957 ; Wills, 1965b; Woggen, 1963).

The content of ascorbic acid was generally higher in tubers treated with irradiation or chemical sprout inhibitor (IPC) than in the control samples (Matanzo and Gonzalez, 1976).

Potatoes treated with X-rays to doses up to 0.09 kGy showed no effect on ascorbic acid but at 0.135 kGy a significant reduction in its content occurred (Berger and Hansen, 1962). X-irradiation of potatoes soon after harvest caused considerable loss of ascorbic acid while irradiation a month or later caused little loss (Metlitsky *et al.*, 1968; Shalinova *et al.*, 1966). Irradiation of tubers soon after harvest resulted in lowering of the ascorbic acid content and the formation of dehydroascorbic acid content was inhibited in such tubers (Maltseva *et al.*, 1967).

Studies with several Indian potato cultivars have shown that ascorbic acid levels decreased during the initial period of storage following irradiation with 0.1 kGy, regardless of the cultivar, when stored either at tropical ambient temperatures or at 15°C. However, on prolonged storage levels was equal to, or even higher than, those of control samples. Irradiated tubers stored at 15°C recorded higher levels of ascorbic acid as compared to controls stored at 2° to 4°C for identical periods (Joshi *et al.*, 1990; Thomas, 1984).

A French research group found that irradiation significantly reduced the ascorbic acid content in potatoes, but after boiling it was rather higher in irradiated tubers than in the nonirradiated control (Anon. 1958). Since this can be interpreted as the result of liberation of the enol group by boiling, they suggested that one portion of ascorbic acid in tubers may be protected from the action of radiation (Matsuyama and Umeda, 1983).

A recent Japanese study on the total vitamin C content of irradiated (0.15 kGy) and nonirradiated potatoes stored at 5°C for 5 months showed no significant differences in the raw tuber or after cooking by steaming, boiling, microwave heating or French frying (Hanai and Nakashima, 1992).

It should be noted that the observed chemical changes in living plant tissues after irradiation are most likely due to complex physiological reactions that may be quite different from radiation chemical effects observed when dilute solutions of pure compounds are irradiated. It is also important to point out that some ascorbic acid is converted into dehydroascorbic acid on irradiation, which is also biologically active.

2.4.3. Other vitamins

Thiamine, riboflavin, and niacin content in potato tubers were not affected by irradiation at sprout inhibiting doses (Lee and Kim, 1972; Metlitsky *et al.*, 1968, Takai and Iwao, 1969; WHO, 1977). However, an increase in riboflavin content was observed with increasing dose (Lee and Kim, 1972) which may be due to increased extractability rather than a net synthesis. No change in vitamin B_1 and B_2 was observed in tubers treated with irradiation or chemical sprout inhibitor (IPC) as compared to controls (Matanzo and Gonzalez, 1976).

Studies with 9 Indian potato cultivars showed that irradiation at 0.1 kGy resulted in decreased levels of carotenoids in the tuber flesh, particularly at 15°C where 50% reduction in its content occurred after 6 months storage. A partial recovery of the carotenoids content occurred when such tubers were reconditioned at 34°-35°C for 6 to 12 days (Janave and Thomas, 1979). The destruction of carotenoids was not related to lipoxygenase activity (Bhushan and Thomas, 1990).

2.4.4. Amino acids and proteins

Some changes were found in the concentration of free amino acids in potato tubers without any alterations in the amino acids constituents of the protein (WHO, 1977). A comparison of the free and protein amino acid content in potato tubers treated by irradiation, chemical sprout inhibitor (MH and IPC), and refrigeration during 5 months of storage revealed no differences in the relative proportions of amino acids, but significant differences existed when compared with untreated controls (Fernandez and Auguirre, 1976). Proline was found to accumulate and a correlation between its content and sprout inhibition by irradiation has been reported (Jaarma, 1966). A decrease of glutamic acid with a parallel increase of_Γ-aminobutyric acid was also observed following irradiation (Fujimaki *et al.*, 1968; Jaarma, 1969a). With the cultivar Dhanshaku, after 15 days of storage following irradiation to 0.07 to 0.3 kGy doses, the contents of proline, aspartic acid, and other aliphatic amino acids increased with increasing dose, while those of the basic amino acids and glutamic acid decreased (Fujimaki *et al.*, 1968).

In the Indian potato cultivar, Up-to-date, aspartic acid, asparagine, threonine, serine, alanine, isoleucine, leucine, lysine and arginine showed increases 24 hr after irradiation at 0.1 kGy, while glutamic acid, proline, methionine, and phenylalanine decreased. Lysine content showed a six-fold increase after 1 week storage, and at 1 month the concentration was still three times higher than the control values (Ussuf and Nair, 1972). However, the amino acid content of potatoes stored for 105 days after irradiation was similar to that of nonirradiated and nonstored potatoes (Fujimaki *et al.*, 1968).

Exposure of potatoes to 0.07 to 0.1 kGy doses 2 weeks after harvest or later did not appreciably affect the nitrogenous substances except during the initial storage period when some of the nonprotein nitrogen increased at the expense of decomposition of protein nitrogen. With prolonged storage, protein nitrogen and nonprotein nitrogen were found to be equal in irradiated and control tubers (Metlitsky *et al.*, 1968). A study of the nutritional quality of potato proteins based on the balance of nitrogen in the rates of growth, amino acid content and available lysine showed no significant effects on the digestibility (net protein utilization) or protein biological value due to irradiation with 0.08 kGy (Varela and Gurbano, 1971).

2.4.5. Greening and glycoalkaloids formation

Greening of potatoes due to chlorophyll formation (Larsen, 1950) can occur either as a result of exposure of tubers to natural light in the field during growth, or to artificial light in storage particularly at cold temperatures (Ramaswamy and Nair, 1974; Schwimmer *et al.*, 1957; Schwimmer and Weston, 1958), on display in the retail stores, in open or transport containers, or in the home. The greening of tubers under light is of concern from the view point of practical marketing (Anon. 1962a) as it reduces the consumer appeal of potatoes in both the fresh market product and in potato chips. The bitter principle in green potatoes is the toxic alkaloid solanine (Hilton, 1951). Chlorophyll synthesis and some products of photosynthesis may be required for the formation of the solanidine ring of solanine (Ramaswamy *et al.*, 1976).

Potato tubers subjected to gamma irradiation for sprout inhibition were found to be more resistant to light-induced greening (Hetherington and MacQueen, 1963). When irradiated and nonirradiated potatoes were placed in consumer polyethylene packages and exposed to both day light and direct sunlight in a window for 8 days, irradiated tubers revealed no greening whereas 60% of the nonirradiated tubers showed on an average 50% greening (Anon. 1962a). Less chlorophyll accumulation was observed in potatoes irradiated within 1 week of harvest and then exposed to continuous light (Winchester *et al.*, 1976a). Greening is a significant problem especially with washed tubers which are sold in small packs. Under normal conditions, greening starts to be a problem after 3 days in the supermarket. With irradiation, greening can be delayed for 9 days, which allows sufficient time to dispose of the product (Jandrell, 1979).

Chlorophyll formation in Russett Burbank potatoes exposed to doses of 0.05, 0.15, 0.5 and 2.5 kGy was inhibited by 62, 67, 75 and 80% when illuminated for 3 days after irradiation (Schwimmer and Weston, 1958). In tubers subjected to 0.4 kGy followed by illumination (75 fc, 60 hr) for 2 months during storage at 4.4°C, chlorophyll formation was reduced by 50% (Gull and Isenberg, 1958).

Studies on chlorophyll synthesis in modified atmospheres showed that irradiation at 0.1 and 0.2 kGy did not inhibit greening of potatoes stored in 0.03 to 15% CO_2, which were illuminated with 3000 lux for up to 20 days. Storage in 15% CO_2 alone caused 50% inhibition in greening upon prolonged illumination (12 days) and irradiation up to 0.4 kGy did not increase the inhibition caused by CO_2, though increasing inhibition of greening was observed at doses from 0.5 to 4 kGy (Ziegler *et al.*, 1968).

Since glycoalakoid formation accompanies greening, it would be reasonable to assume that irradiation may also delay the formation of solanine. A 70% reduction in chlorophyll synthesis and solanidine formation has been reported in Kufri Chandramukhi potatoes irradiated to 0.1 kGy as compared to those without irradiation (Nair *et al.*, 1981). However, another study showed that a dose of 0.1 kGy alone or in combination with 15% CO_2, reduced chlorophyll formation in Russett Burbank potatoes exposed to light (100 fc) for 5 days but glycoalkaloid synthesis was not affected (Patil *et al.*, 1975). Gamma irradiation at 2 kGy did not inhibit the light-induced glycoalkaloid formation in potato tubers while the glycoalkaloids induced by wounding or mechanical damage to the tubers was inhibited by doses 0.25 to 2 kGy (Wu and Salunkhe, 1971). Similarly, doses at 0.1, 0.5 and 3 kGy had no effect on the glycoalkaloid content of potatoes during a 4 month storage period (Bergers, 1981). Irradiation at a dose of 0.1 kGy was more effective than 1 kGy in inhibiting the synthesis of total glycoalkaloids in Kennebec and Russet Burbank potatoes during storage (Mondy and Seetharaman, 1990).

It is to be noted that the lack of inhibition of chlorophyll and glycoalkaloids formation in potatoes exposed to high doses or under modified atmospheres has not much practical importance.

2.4.6. Flavor and pungency of bulbs

Since onions and garlic are primarily used for their flavoring properties in foods, many studies have been undertaken to determine the effect of sprout inhibiting doses of gamma irradiation on the development of characteristic flavor, odor and lachrymator and the related enzymes.

Based on subjective evaluation, some of the earlier investigators had noted that irradiation makes the characteristic odor and pungency of onions milder (Brownell *et al.*, 1957a; Lewis and Mathur, 1963; MacQueen, 1965; Mathur, 1962; Nuttall *et al.*, 1961) while some others have not found differences in quality either in raw or in cooked conditions (Truelsen, 1960). Though a measure of volatile sulfur or volatile reducing substances may not give a fair estimate of the pungency, studies based on these criteria indicate a reduction in the pungency of irradiated onions (Salems, 1974) while a few other results do not show any such effect (Dallyn and Sawyer, 1954; Kim *et al.*, 1970; Mumtaz *et al.*, 1970).

Investigations employing the more sensitive gas chromatographic techniques also seem to show divergent results with regard to the effect of irradiation on flavor, pungency, and lachrymatory principles of onions (Bandyopadhyay *et al.*, 1973; Matsushima *et al.*, 1974; Nishimura and Mizutani, 1975a,b; Nishimura *et al.*, 1971a, 1971b; Thomas *et al.*, 1986). In Senshu Yellow onions a combination of sensory tests and quantification of the individual volatile components showed that the lachrymatory character and pungent flavor decreased to a lesser extent after 0.07 and 0.15 kGy irradiation whereas a remarkable reduction occurred after 0.7 and 7 kGy (Nishimura *et al.*, 1971b). The relative amounts of propionaldehyhde (assumed to be one of the breakdown products of the lachrymator substance thiopropanal S-oxide), n-propyl mercaptan (Sweet substance) and di-n-propyl disulfide (pungent flavor substance) in onions stored for 0, 5, 10 and 30 days were decreased remarkably at 0.7 and 7 kGy with increasing storage period at room temperature (20° to 25°C) as well as at low temperature (4°C). However, at 0.07 kGy these components were affected little (Nishimura *et al.*, 1971b).

A study of the content of the lachrymator factor thiopropanal S-oxide which is produced from S-(*trans*-1-propenyl) L-cystine sulfoxide by the action of allinase revealed that its development decreased with increasing dose and storage at room temperature (15° to 24°C). However, at 0.03 kGy, a dose sufficient to inhibit sprouting, both the lachrymatory character and the development of thiopropanal were little affected (Nishimura and Mizutani, 1975b). It should be emphasized that the changes observed at very high dose levels of 0.7 and 7 kGy have no practical significance. Moreover exposure of onion bulbs to such high doses can cause severe damage to the commodity and therefore is not justifiable from technological considerations.

Contrary to the above findings, studies employing gas liquid chromatography, thin-layer chromatography, infrared spectroscopy and sensory tests of head space gases showed no changes in the flavor components of Red Globe onions irradiated with doses of 0.06, 0.1, 0.2 and 0.5 kGy and stored at ambient temperature (25° to 30°C up to 3 months (Bandyopadhyay *et al.*, 1973). Also, no appreciable differences were observed in the pungency and flavor strength in irradiated (0.06 kGy) onions under commercial conditions (Thomas *et al.*, 1986).

Although the results of a few studies seem to support the view that the reduction in the flavor, odor and lachrymatory principles observed in irradiated onions may be due to a partial inactivation of allinase, a recovery in enzyme activity takes place during storage in onions irradiated with sprout inhibiting dose levels (El-Sayed and El-Waziri, 1977; Kawakishi *et al.*, 1971) and the flavor characteristics are restored to levels comparable to nonirradiated onions stored under similar conditions.

In garlic bulbs irradiation at 0.1 kGy had no influence on the total sulfur and thiosulfonate content during storage at 3±1°C and 80±5% RH for 10 months, though the content of both components showed a significant reduction in control and irradiated after 6 to 8 months storage compared to initial values (Kwon *et al.*, 1989). Similarly, no appreciable changes were detected in either gas liquid chromatograms or visible and infra-red spectrographs of etherial extracts of 'red' garlic bulbs irradiated with 0.05 kGy and stored in a commercial warehouse (6 to 32°C, RH 58 to 86%) for 6 months (Curzio and Ceci, 1984). Enzymic pyruvate which is closely related to flavor development in crushed garlic increased in both control and irradiated bulbs during storage, the average values being higher in irradiated bulbs (Ceci *et al.*, 1991). The activity of Γ-glutamyl transpeptidase was also found to be relatively higher in irradiated garlic (Ceci and Curzio, 1992).

2.5. TECHNOLOGICAL PROPERTIES OF IRRADIATED BULBS AND TUBERS

2.5.1. Weight loss

A Canadian study showed that total weight loss due to sprouting and shrinkage of onion bulbs irradiated with 0.06 and 0.076 kGy was 5.7% as against 23.2% for the nonirradiated bulbs after 5 months storage at 12.8°C (Anon. 1962d). In the cv "Valenciana Sintetica 14" grown in Argentina, the weight loss at the end of a 270 day test storage in a commercial warehouse (6 to 32°C, RH 50 to 90%) was found to be 43.3% in the control as against only 22.8% in 0.03 kGy treated samples (Curzio and Croci, 1983). In a pilot-scale study conducted in India the weight losses due to desiccation after 4.5 months storage at ambient temperature under commercial conditions (23° to 32°C, RH 60 to 80%) was 15.2% in irradiated (0.06 kGy) samples as against 27.7% in nonirradiated bulbs (Thomas *et al.*, 1986). The increased desiccation in control onions was attributed to sprouting and consequent rise in transpiration losses. On the other hand no significant differences in weight losses were found between unsprouted control and bulbs irradiated with doses ranging from 0.032 to 0.095 kGy (Nuttal *et al.*, 1961).

Reduction in weight losses in storage similar to that of onions have been observed by several workers in irradiated garlic bulbs. In the Cv "Rosado Paraguayo" grown in Argentina the weight loss in irradiated (0.05 kGy) garlic bulbs at the end of 300 days storage (6°-32°C, RH 40-50%) was 22% as compared to 43% in the control (Croci *et al.*, 1990). In the cv "Red" the weight losses were 55% and 24% in the control and irradiated (0.03 kGy) respectively at the end of 300 days storage at 6° to 32°C, RH 58-86% (Croci and Curzio

1983a). Weight losses in the same cultivar stored for similar durations at 15° to 18°C, RH 70-80% were 60 and 23% respectively in control and irradiated lots (Curzio *et al.*, 1983). Many other studies have shown less weight losses in stored garlic bulbs subjected to low doses of irradiation for sprout control when compared to nonirradiated samples stored under similar conditions (Abdel-Al, 1967; Brunelet and Vidal, 1960; El-Oksh *et al.*, 1971; Kwon *et al.*, 1985; Mathur, 1963a; Thomas, 1993).

In potatoes the weight loss due to shrinkage increased in control tubers from 4 to 34% during 5 months storage at 12.8°C associated with sprouting, while in irradiated (0.075 kGy) tubers weight loss increased from 4 to only 9% during the same period (Anon. 1962b,c). A similar reduction in weight losses in four cultivars irradiated to 0.05 to 0.15 kGy was observed during storage at 10°C (Sawyer and Dallyn, 1961).

In 3 Japanese potato cultivars the weight loss during storage at room temperature was reduced by 0.07 and 0.15 kGy but not during storage at 5°C (Umeda *et al.*, 1969a, b). A commercial scale study involving 5 Japanese cultivars under varying storage regimes confirmed that irradiation prevented weight loss as compared to nonirradiated potatoes, especially at 7°C storage (Umeda, 1978; Matsuyama and Umeda, 1983). In a semi-commercial experiment with 2 potato cultivars grown in Pakistan the weight losses during 6 months storage at 20°C was 28 to 51% in nonirradiated as compared to 17 to 40% in samples irradiated at 0.1 kGy (Khan *et al.*, 1986).

A progressive reduction in weight losses in yams (*D. rotundata*) was observed with increasing doses from 0.025 to 0.15 kGy after 5 months storage in a yam barn (25° to 37°C, RH 50 to 85%), the loss being 39.7% in controls as compared to only 17.7% in 0.15 kGy irradiated (Adesuyi and Mackenzie, 1973). A dose between 0.05 to 0.20 kGy caused more than 50% reduction in weight loss in 9 yam cultivars grown in Nigeria in comparison to controls (Adesuyi, 1976; 1978).

2.5.2. Specific gravity and firmness

Irradiation at sprout inhibiting doses or doses 2 to 6 fold as great as those required for sprout inhibition were not found to affect the specific gravity in several cultivars of potatoes after storage at -0.5° to 18.8°C (Schreiber and Highlands, 1958b) or at 5°C and 12.8°C following exposure to doses of 0.045 to 0.135 kGy (Ellis *et al.*, 1959). Sound bulbs from irradiated onions were found to be firm with skins relatively intact and bright in color (Nuttal *et al.*, 1961). Other studies also showed that irradiation maintained the firmness of bulbs and tenderness of the fleshy scales (Grunewald, 1978; Kalman, 1982). On the contrary, in one study the irradiated onions were found to be softer due to the stimulation of inner bud development followed by necrosis and shrinkage of such buds and the consequent formation of hollows during storage in a naturally cooled cellar room (Zehnder, 1984).

2.5.3. Color

Irradiation at doses of 0.06 to 0.5 kGy neither affected skin color immediately nor influenced the rate of fading of the bulb color during 3 month storage at ambient temperatures (25° to 30°C) in the cultivar "Nashik Red Globe" as evidenced by their anthocyanin content (Bandyopadhyay *et al.*, 1973). Similar observation were made in the cultivar "Giza-6" exposed to 0.06 kGy (Salems, 1974).

2.5.4. Storage rots

Generally speaking, the irradiation dose levels employed for sprout inhibition are too low to affect the microbial population. At the same time, from the point of view of storage, it is important that the susceptibility of bulbs and tubers to spoilage microorganisms are not increased after irradiation.

While some researchers have reported a decrease in storage rots of onions after irradiation (Lewis and Mathur 1963; MacQueen, 1965; Mumtaz *et al.*, 1970; Van Kooy and Langerak, 1961) a few others have found that irradiation may increase storage rots (Agbaji *et al.*, 1981; Dallyn and Sawyer, 1954; Nandpuri *et al.*, 1969). Storage rots are not significantly increased after irradiation when bulbs are stored in well aerated storehouses, but storage in poor ventilated storehouses under tropical temperatures may lead to higher losses by spoilage pathogens compared to nonirradiated controls (Thomas *et al.*, 1986). During extended storage irradiated onions appear to be more susceptible to microbial attacks than the nonirradiated ones (Nuttal *et al.*, 1961; Skou, 1971). Results of several laboratory scale as well as pilot scale storage studies generally show that when well-cured and healthy bulbs of good quality are irradiated during the dormancy period to the minimum dose needed for sprout inhibition and when good storage management is practiced, rots are not significantly increased (Thomas, 1986).

Significant decrease in neck rot with increasing doses up to 7.5 kGy of 1 MeV electrons was observed (Van Kooy and Langerak, 1961), probably due to the high doses given towards the neck leaving the rest of the bulb protected. The increased storage rot observed in onions after gamma irradiation with doses in the range of 0.5 to 5 kGy (Chachin and Kurosaki, 1971; Skou, 1971) has no practical significance.

The importance of storage rots in irradiated potato tubers has been emphasized (Beraha *et al.*, 1959; Brownell *et al.*, 1957b; Buitelaar, 1970; Duncan *et al.*, 1959; Eugene, 1968; Heiligman, 1957; Hooker and Duncan, 1959; Metlitsky *et al.*, 1967; Mukhin, 1959; Mukhin and Panasenko, 1957; Sawyer and Dallyn, 1961; Schreiber and Highlands, 1958a; Skou and Henricksen, 1963; Thomas *et al.*, 1978a,b; Waggoner, 1955). The susceptibility to microbial rot may vary with cultivar, and, in general, increases in proportion to the radiation dose (Duncan *et al.*, 1959), the severity of mechanical injuries at the time of irradiation (Duncan *et al.*, 1959) and higher storage temperature (Thomas *et al.*, 1978a,b). The increased rotting tendency after irradiation has been ascribed to disturbance in general metabolism (Metlitsky *et al.*, 1967; Rubin and Metlitsky, 1958), inability to form a normal wound periderm (Brownell *et al.*, 1957b; Henriksen, 1960; Metlitsky *et al.*, 1967; Mukhin, 1959; Mukhin and Salkova, 1964; Sparks and Iritani, 1964; Thomas, 1982), and a decrease in natural resistance or phytoimmunity due to reduced synthesis of phytoalexins (El-Sayed, 1975; 1978; Farkas, 1976; Ghanekar *et al.*, 1983) and phenolics (Mukhin, 1963; Ogawa *et al.*, 1968; Ramamurthy *et al.*, 1992; Thomas, 1982; Thomas and Delincee, 1979). However, in one study phytoalexin concentration in response to infection by *Phytophthora megasperma* was found to be higher in irradiated potatoes (Schmidt *et al.*, 1985) suggesting that phytoalexin accumulation is not clearly related to the mechanism of resistance against fungi.

Curing of potato tubers before irradiation can reduce rotting during subsequent storage, because curing will allow the healing of wounds inflicted during harvest. It is thus important that irradiation of tubers in commercial practice should be done under conditions favorable to rapid formation of wound periderm and mechanically damaged parts. Many studies have shown that when good quality potatoes suitable for long term storage were irradiated and not mishandled during and after irradiation, there was no effect or only slight effect on the rate of decay during storage (Baraldi, 1978; Diehl, 1977; Duncan *et al.*, 1959; Metlitsky *et al.*, 1967; Rubin *et al.*, 1959; Sparks and Iritani, 1964; Shirsat *et al.*, 1991).

Studies on the effect of wounding before or after irradiation on the incidence of storage rots in four potato cultivars which were artificially inoculated with *Erwinia caratovora* and *Fusarium sambucinum* showed that nonwounded, nonirradiated tubers developed little storage rot at sprout-inhibiting levels of irradiation. Wounded tubers exposed to 0.025 to 0.15 kGy developed appreciably more storage rot than did nonwounded tubers, suggesting that careful handling before and after irradiation is important in avoiding losses (Duncan *et al.*, 1959).

In experiments on the irradiation of completely healthy tubers, the losses from diseases, particularly *Fusarium* rot, were small (2%) and the same as in the control tubers for 8 months of storage (Metlitsky *et al.*, 1967). In a comparative study of irradiated and chemically sprout inhibited "Bintje" potatoes no differences were observed to infection by *Phoma*, *Fusarium* and *Cephalosporium* during storage at 9°C, RH 90-95%, while irradiated Saturna potatoes were affected more frequently (Buitelaar, 1970). Similar studies with German cultivars showed that rotting was low in CIPC-treated potatoes and slightly higher in irradiated ones, the difference being significant in those batches which received rough mechanical treatment (Diehl, 1977). Likewise, experiments on the application of irradiation for long term storage of the major Italian potato cultivars confirmed that irradiation and chemical treatment do not encourage rotting when potatoes, healthy at harvest, are handled gently during treatment and storage (Baraldi, 1978). In a semi-commercial trial in Pakistan, rotting losses were 17-40% in 0.1 kGy irradiated potatoes as against 20-45% in nonirradiated samples during 6 months storage at 20°C (Khan *et al.*, 1986).

For industrial scale irradiation, it may be advantageous to allow wound healing of the harvested tubers to take place in containers in which the tubers are to be irradiated and stored, thus minimizing handling damages during and following irradiation. This would demand for changes in the established or existing handling procedures and the introduction of a crate system for transport and storage.

2.5.5. Wound healing

As stated briefly in the earlier Section, the increased susceptibility of irradiated potatoes to rotting has been related to the inability of the irradiated tubers to form a normal wound periderm (Henriksen, 1960; Lee *et al.*, 1973; Metlitsky *et al.*, 1957; 1967; Mukhin, 1959; Mukhin and Salkova, 1964; Thomas, 1982). The wound-healing process involves suberization - deposition of suberin, a lipid phenolic polymer on the cell layers below the wound surface - followed by formation of wound periderm or cork. Both wound-induced periderm formation and sprouting involve mitotic activity and cell division. The suberization process is not inhibited by sprout inhibiting doses of 0.10 kGy (Metlitsky *et al.*, 1957; Thomas, 1982; Thomas and Delincee, 1979) while doses as low as 0.02 to 0.03 kGy, which had no effect on sprouting, inhibits wound periderm formation (Brownell *et al.*, 1957b; Thomas, 1982). As suberization occurs slowly and in the absence of a wound periderm, disease causing pathogens manage to penetrate into the tuber causing faster development of rot. Therefore, potatoes after harvest should be stored for 2 weeks at 15° to 20°C with a rather high relative humidity and good ventilation for rapid wound healing before they are irradiated (Metlitsky *et al.*, 1957).

The effect of irradiation on wound healing appears to be less of a problem in onions and yams.

2.5.6. Peeling and trim losses

The reduction of peeling and trim losses would be advantageous for consumers as well as for the prepeeled potato industry (Matsuyama and Umeda, 1983). Irradiation inhibits greening and solanine formation in the surface layer of tubers (Anon., 1962c; Schwimmer *et al.*, 1957) and this may reduce peeling losses (Sreenivasan, 1974). In Sebago and Russett Rural potatoes, least peeling and trim losses were found in tubers irradiated with 0.05 and 0.1 kGy (Heiligman, 1957). In the cultivar Sebago irradiated with 0.10 kGy and stored at 22°C for 2 months, the total peeling and trimming losses were 22% compared to 32% in the nonirradiated tubers.

2.5.7. Discoloration

2.5.7.1. Inner bud discoloration of bulbs

The discoloration or darkening of inner buds or the growth center near the disc region in bulb crops irradiated for sprout inhibition is a widely occurring phenomenon (Thomas, 1986). The discoloration occurs irrespective of cultivar differences, time of irradiation after harvest, irradiation dose and, post-irradiation storage conditions, although these factors can modify the intensity and the extent of the darkening. The general impression is that this discoloration does not make the onions and garlic objectionable for most kinds of use including the manufacture of dehydrated products.

In onions irradiated during the dormancy period, the discoloration is limited to a very small area comprising of the meristem tissue. In bulbs in which the inner buds have developed, irradiation causes the death of the buds and consequently the area of discoloration would depend upon the size of the inner buds at the time of irradiation. Under certain storage conditions, irradiation during the nondormancy period can cause a transient stimulation of sprout growth and these sprouts die off later, leaving a larger area of discolored tissues (Matin *et al.*, 1985; Thomas *et al.*, 1975).

A few studies seem to suggest a correlation between dose and the degree of discoloration (Brunelet and Vidal, 1960; MacQueen, 1965) while no such effect was observed by others (Dallyn and Sawyer, 1954; Temkin-Gorodeiski *et al.*, 1972; Thomas, 1986, Thomas *et al.*, 1975). Discoloration of inner buds was observed even at doses as low as 0.0075 to 0.01 kGy which had no effect on sprouting (Temkin-Gorodeiski *et al.*, 1972). In the onion cultivar Alsogodi grown in Hungary no discoloration of the inner bud occurred in 0.05 kGy irradiated bulbs during storage up to 8 months under ambient conditions (Kalman, 1982).

The inner bud discoloration of irradiated onions can be prevented by storage at low temperatures. In 3 cultivars grown in Israel darkening was not observed during storage up to 8 months at 0°C, though slight darkening sometimes appeared when these onions were stored subsequently at ambient temperatures of 10° to 30°C (Temkin-Gorodeiski *et al.*, 1972). In the Japanese onion cultivar "Sapporoki" irradiated with 0.03 to 0.07 kGy, browning of inner buds was prevented by storage at 3°C and such onions retained good market quality for 1 month when transferred to ambient temperatures (Takano *et al.*, 1974a). Results of a few other studies indicated that the time at which the browning developed was dependent on the storage temperature, those stored at higher temperatures developing discoloration earlier than those held at lower temperatures (Grunewald, 1978; Thomas, 1986).

A pale yellow to yellowish brown discoloration of internal sprouts or growth centers has been found to occur in garlic bulbs stored for periods beyond 6 months at 0° to 5°C (Lustre *et al.*, 1981) and after 5 months at 6° to 32°C (Croci and Curzio, 1983).

2.5.7.2. *After-cooking darkening of potatoes*

A bluish-grey discoloration usually referred to as "after-cooking darkening" appearing in tubers shortly after cooking has been reported for many potato cultivars grown in different parts of the world. This darkening is attributed to the formation of ferrous-phenolic complexes on cooking, which on exposure to air turn to the bluish dark ferric-phenolic complexes. Agronomic and climatic factors as well as the content of iron, orthodiphenols, organic acids and pH of the tuber flesh are known to influence the darkening tendency (Hughes *et al.*, 1962; Smith, 1977).

Gamma irradiation at sprout inhibiting dose levels may induce or enhance the after-cooking darkening in whole tubers (Buitelaar, 1974; Sawyer, 1956; Sawyer and Dallyn, 1961; Stone *et al.*, 1966; Thomas, 1981; Thomas and Joshi, 1977; Thomas *et al.*, 1979; Truelsen, 1964) as well as in processed products such as french fries and chips (Buitelaar, 1974; Buitelaar *et al.*, 1973; Penner *et al.*, 1972; Sparrenburg and Buitelaar, 1977). A study of 10 cultivars irradiated with electron beams on two sides showed that in boiled potatoes, discoloration occurred faster in electron-irradiated tubers, but it was better than in the gamma irradiated tubers. Color of crisps made from electron-irradiated potatoes was not satisfactory in the beginning of the season but after storage crisps made from electron-irradiated potatoes were equal to chemically (IPC and CIPC) treated ones and very much better than crisps made from gamma-irradiated potatoes. Pre- fried chips made from electron-irradiated tubers were better than chips made from gamma-irradiated ones and showed only a slight discoloration towards the end of the season and very little difference with chemically treated tubers (Buitelaar, 1974). These results and other studies (Berset and Sandret, 1976) suggest that discoloration in boiled and processed potatoes can be minimized by the use of electron irradiation instead of gamma irradiation.

The irradiation induced darkening of boiled tubers appears to be related to increased polyphenols formation and reduced citric acid levels in the tuber flesh (Berset and Sandret, 1976; Thomas *et al.*, 1979). Prepeeling of the tubers prior to cooking, soaking and cooking of tubers in solutions of diaminoethane-tetra acetic acid sodium salt (EDTA) or citric acid, and reconditioning of tubers at 34° to 35°C reduces the after-cooking darkening (Thomas, 1981; Thomas and Joshi, 1977). The use of sodium acid pyrophosphate to prevent the occurrence of a grey discoloration in processed potato products such as dehydrated flakes and granules, oil blanched french fries, potato salad, as well as in boiled or steamed whole tubers is a commercial practice (Smith, 1977). A similar approach could be adopted for processed products made from irradiated potatoes.

2.5.7.3. *Other types of discoloration in potatoes*

Increased incidence of black spot or internal blackening was reported in some cultivars grown in the USA (Sawyer and Dallyn, 1961), Denmark (Skou, 1967), and Russia (Metlitsky *et al.*, 1967) after exposure to sprout inhibiting doses of gamma rays.

The browning of the tissues around the cortex region and vascular bundles in tubers irradiated to sprout inhibiting dose levels appears to be limited only to some potato cultivars grown in Japan (Ogata *et al.*, 1970; Ogawa and Uritani, 1970; Ojima *et al.*, 1970; Tatsumi *et* *al.*, 1972,1973). This type of browning could be avoided by irradiating the tubers 2 to 2½ months after the harvest, and by storage at low temperatures after irradiation (Ogata *et al.*, 1970; Ojima *et al.*, 1970b). Potatoes from the main growing district of Hokkaido did not show browning (Umeda, 1975). A commercial scale potato irradiation facility was established in this district in 1973 and has been processing 15 000 to 20 000 tons of potatoes annually since then (Matsuyama and Umeda, 1983) indicating that browning around the cortex region has not been a commercial problem with potato varieties processed in this irradiator facility.

2.5.8. Effect on organoleptic qualities

The evaluation of cooking qualities such as color, texture, flavor, off-flavor and preferences have not shown any significant change in culinary properties between irradiated and unirradiated potato tubers and onion bulbs during extended storage (Anon. 1963a,b; Brownell *et al.*, 1954; Burton and Hannon, 1957; Dallyn and Sawyer, 1959; Gardner and MacQueen, 1965; Heiligman, 1957; Josephson *et al.*, 1977; Nuttall *et al.*, 1961; Ogata *et al.*, 1959a; 1959b; Rubin and Metlitsky, 1958; Skou, 1971; Sparrow and Christensen, 1954; Sparrow and Schairer, 1955; Umeda, 1969). Sweetening and enhanced after-cooking darkening have been observed during storage of irradiated potatoes (Asselbergs and Wethington, 1960; Gardner and MacQueen, 1965) and sweetening after higher doses (Mikalsen *et al.*, 1958; Pedersen, 1956; Sparrow and Christensen, 1954). The characteristic flavor of onions was not seriously altered by irradiation (Ogata *et al.*, 1959b) and no off-flavor developed after irradiation (Nuttall *et al.*, 1961). However, irradiated onions were reported to be less astringent and lachrymatory, milder in flavor, slightly sweeter and required shorter cooking time for the same degree of tenderness as compared with the unirradiated bulbs (Lewis and Mathur, 1963; MacQueen, 1965; Nuttall *et al.*, 1961; Ogata, 1973; Umeda, 1975).

2.5.9. Processing qualities of irradiated onions and potatoes

In a series of pilot scale experiments carried out in Hungary, onions irradiated to 0.05 kGy were tested for their processing qualities after the end of the storage period. The yield of cleaned unirradiated onions prepared for drying was 29% of the original, while the yield of irradiated samples was 55% of the original. The dehydrated onions prepared from irradiated samples were of better quality than the controls (Farkas, 1976). The quality of dried onion flakes prepared from irradiated samples was reported to be excellent when subjected to stringent quality tests (Anon., 1978). In four Hungarian-grown cultivars, the quality of the dried onion flakes made from 0.05 kGy treated bulbs had 30 to 70% less bud parts than in the control bulbs (Kalman *et al.*, 1978). Results of a study conducted in Egypt also showed that irradiation at 0.06 kGy did not result in any difference in the dehydration ratio or color of the flakes made from Giza-6 cultivar of onions stored for 6 months (Salems, 1974).

A few studies, on the other hand, have reported that the inner bud discoloration in irradiated onions may lower the quality of the dehydrated onion slices or powder (Anon., 1962c; Dallyn and Sawyer, 1954). Cold storage at 3° to 5°C after irradiation may be effective to abolish the disadvantage due to the darkening of inner buds (Anon., 1962c).

Studies carried out in four provinces of eastern Canada with a total of 400t of potatoes have shown that a dose of 0.08 kGy provided excellent control of sprouting in all storage conditions regardless of cultivar, storage temperature, date of irradiation, method or length of storage. Irradiated potatoes were successfully processed into chips, mashed, flakes, french fries, and prepeeled fresh boilers and were acceptable to consumers (Anon., 1963b). In another study with Ontario grown Kennebec potatoes irradiated with 0.08 kGy and stored for 10 months under controlled storage conditions, no undesirable effects were observed on the chipping qualities of tubers.

A comparative study of the storage and processing qualities of Pontiac, Kennebec, and Russett Burbank potatoes, sprout inhibited by irradiation and chemicals (CIPC, MH-30) conducted in the USA showed that the processing quality was not affected by treatments *per se* and no apparent differences in flavor and color of dehydrated slices and flakes, chips or table stock were caused by a specific sprout inhibition method (Kwait, 1965). Similarly, another study found that both irradiated and chemically sprout-inhibited Russett Burbank potatoes produced generally comparable and commercially acceptable processed products, though irradiated potatoes and products from it were more prone to discoloration (Freund, 1965).

A recent study on the processing quality of 5 Indian potato cultivars, after inhibition of sprouting by irradiation (0.1 kGy) or CIPC treatment showed that neither of the treatments affected the quality of french fries and chips, when stored at 15° and 20°C for up to 6 months, but the storage at 10°C resulted in darker products due to higher levels of reducing sugars (Shirsat *et al.*, 1994). Other reports indicate that in Russett Burbank potatoes grown in Canada (Borsa *et al.*, 1989), and in Kennebec, Wu Fioon and Cardinal, grown in Taiwan (Liu *et al.*, 1990) irradiation followed by extended storage at 10°C did not affect their chipping quality.

Potatoes of the cultivars Bintje and Saturna grown in Germany treated with 0.085 or 0.15 kGy of X-rays and stored for 6 to 8 months and processed under industrial conditions showed a grey discoloration in pommes frites and dried potatoes, and, darker chips than the chemically treated (CIPC and IPC) group in one year (Penner *et al.*, 1972a) but in another year chips of good quality were produced from cultivars Saturna, Tasso, Hansa and Hela (Penner *et al.*, 1972b). Several other studies also showed that irradiation did not have any significant effect on the qualities of potatoes for processing into chips, instant mashed potato flakes, frozen french fries, and fresh prepeeled boilers (MacQueen, 1965; Tankano *et al.*, 1974b; Umeda, 1969).

2.5.10. Effect on potato tuber moth

One of the most destructive postharvest pests of the potato under the warm sub-tropical and tropical regions is the potato tuber moth *Phthorimaea operculella* (Zeller). It has been reported that irradiation at 0.01 kGy prevented hatching of eggs and adult emergence from infested tubers stored under tropical ambient conditions (Thomas *et al.*, 1978a). While irradiation at 0.1 kGy completely inhibited adult emergence in tubers infested with eggs and early larval instars, a dose of 0.2 kGy was required to obtain the same results in tubers infested with late larval instars (Harwalkar and Rahalkar, 1971). Another study showed that eggs and newly hatched larvae survived doses up to 0.08 kGy. Immature stages that developed from irradiated eggs showed retardation of development and reduction in size and weight and the adult moths that emerged were malformed. Females were more sensitive and all doses delivered to eggs reduced the fecundity of adults that developed from them. Doses of 0.24 to 0.96 kGy given to mature larvae prevented pupation, lesser doses retarded pupal development. One-day-old pupae succumbed to 0.06 kGy while normal adults emerged from pupae exposed to eight times that dosage at the eighth day of pupal stage (Elbardy, 1965).

2.6. TEST MARKETING AND CONSUMER ACCEPTANCE TRIALS

Market trials are important pre-requisite to commercialization of irradiated foods. Test marketing and consumer acceptance studies of onions and potatoes sprout inhibited by gamma irradiation have been conducted in some countries where the appropriate clearances have been granted. It has been reported that a total of about 2000 t of irradiated onions have been produced and marketed up to 1980 in France, Hungary, Israel, Italy, the Netherlands, and Thailand (Anon., 1980).

In Hungary, a series of market testing trials on onions irradiated with 0.05 kGy to prevent sprouting and subsequently stored for 6 to 7 months have not shown any objection from either consumers or marketing companies when the irradiated onions were sold through retail outlets in several cities (Anon., 1977a; Kalman, 1979). In a market test carried out in Israel (Anon., 1970), irradiated onions were compared for consumer preference along with onions from cold storage. Though the preference for irradiated onions was not constant, on average it was of the order of 2 to 1 compared with onions from cold storage. Preference for irradiated onions increased when the price was higher and fell when the price was lower than that of onion from cold storage, indicating the influence of other variables on the consumer preference.

Consumer surveys in Greenland (Skou, 1967) showed that irradiated potatoes had the best outer appearance throughout as compared to potatoes sprout-inhibited by Fusarex. Chemically treated tubers sprouted after a shorter or longer period depending on the temperature in storage rooms. In one survey, a certain amount of irradiated tubers showed internal blackening or black spots later in the storage period and a slight, but significant increase in storage rot occurred in irradiated potatoes. Although for a period immediately after treatment, a sweeter taste was reported in irradiated potatoes, it seldom affected their acceptability. Irradiated tubers stored at a higher temperature scored higher acceptability in the later storage period.

In Israel, 70 t of irradiated potatoes were produced in 1968 and sold through supermarkets followed by a large quantity in 1969 (150 t) sold through all retail channels including green grocers and open markets (Anon., 1973; Padova *et al.*, 1968). The products were sold in 2 kg net bags bearing labels "food stuffs preserved by irradiation". This activity was preceded and accompanied by a public campaign carefully planned by a team well qualified in business management, marketing, and home economics. Under these conditions, there was practically no consumer resistance to the irradiated product. In fact, a majority of consumers preferred the irradiated product in comparison to cold stored (4°C) potatoes provided that good quality was apparent.

In Bangladesh irradiated onions test marketed periodically during post-irradiation storage of 8 months were preferred by traders and consumers (Matin and Bhuiya, 1990; Matin *et al.*, 1988). Irradiated (0.08-0.10 kGy) potatoes, under semi-commercial studies, were test marketed during off-season months using normal trading channels. Consumers preferred irradiated potatoes although some remarks on colour were received (Hossain *et al.*, 1984-85). An industrial enterprise has successfully marketed good quality chips made from irradiated potatoes.

In a consumer test with potatoes irradiated for sprout inhibition with a dose of 0.12 kGy in Federal Republic of Germany, 34 participating families stored the irradiated and nonirradiated potatoes in their homes and periodically judged the tubers for their appearance, sprouting, rotting, suitability of different ways of preparing the meal, and the sensory properties of the cooked meal (Grunewalld, 1970). The majority of the participants rated the irradiated potatoes as high as or higher than the nonirradiated potatoes. However, a trained panel rated the irradiated potatoes slightly lower due to minor color deviation.

A combined industrial scale study on potato irradiation was made by German and French workers (Anon., 1977b). Nearly 50 t of potatoes were irradiated with a mobile ^{137}Cs irradiator in the premises of a chip manufacturing company in Bavaria and stored in the storage facilities until the potatoes were processed into crisps. Consumer acceptability studies indicated that while no significant differences could be detected for the criteria of "smell" and "crispness", the darker brown color of crisps prepared from irradiated tubers led to a less positive assessment of color and taste in comparison to crisps made from chemically treated samples. No aversion to the irradiation treatment was noted from this consumer test and two thirds of the 500 or more participants declared that they would be prepared to pay a 5% higher price for crisps made from potatoes which had not been chemically treated.

In a study on public acceptance of irradiated potatoes in Chile (Cruz, 1977), 164 t of different varieties were irradiated to 0.10 kGy and stored for several months at 6° to 10°C, RH 80 to 85%. No changes were observed in organoleptic or culinary qualities during a period of 8 months and consumer acceptability tests involving 4000 persons showed a slight preference for the irradiated product as compared with the untreated ones. Test marketing trials conducted in Hungary (Anon., 1972), Italy (Baraldi, 1978), South Africa (van der Linde, 1978) and Uruguay (Merino, 1978) all have shown positive consumer acceptance for irradiated potatoes.

During the last decade several countries have made significant progress towards commercialization of food irradiation and have carried out market tests. In a market trial with irradiated onions and garlic in Argentina, 94.7% of the consumers rated irradiated onion as "very good" while 32.4% and 61.3% rated irradiated garlic as "very good" and "good' respectively. In these trials garlic and onion bulbs harvested in December and February respectively and irradiated within 30-40 days post harvest to a dose of 50 Gy were market tested in October when only bulbs of inferior quality are available. The market test was preceded by a consumer education campaign on the benefits of irradiation processing (Curzio *et al.*, 1986b).

In Poland, market tests with onions irradiated to 50 Gy after 4 weeks of harvest and stored for 7-8 months in naturally ventilated cool store houses were conducted through several self-service shops in Warzaw and Poznan every year during 1984-88. Results indicated that consumers were not opposed to irradiation when the advantages were evident. Almost all of the consumers confirmed a longer shelf-life of irradiated onions under household conditions without losses due to sprouting, rooting or desiccation. About 95-97% consumers declared their willingness to buy irradiated onions in the future (Gajewski, 1989).

A recent compilation of market trials with irradiated potatoes, onions and garlic conducted from 1984 to 1989 in Argentina, Bangladesh, the People's Republic of China, Cuba, Pakistan, the Philippines, Poland and Thailand demonstrates that consumers showed no objection to irradiated products. In many instances consumers showed preference for irradiated products due to its higher quality (Anon. 1990). About 1250 t of onion and 4000 t of garlic were marketed in China during the above period. Subsequently it has been reported that 960 t of potatoes, 1250 t of onions and 20,300 t of garlic were test marketed in China during 1985-1990 (Chen *et al.*, 1991).

2.7. COMMERCIAL IRRADIATION

The only industrial scale irradiation facility currently in commercial operation for irradiation of potatoes for sprout inhibition was set up in 1973 by the Shihoro Agricultural Co-operative Association at Shihoro in Hokkaido, Japan. Production of potatoes in Shihoro was 250 000 t per year of which 180 000 t were used for starch manufacture and the rest was marketed for general distribution for further use as table potatoes and for processing. The storage capacity for potatoes is 70 500 t (Umeda, 1983). This Co-operative processes about 17 000 t of potatoes each year into snacks such as chips, shoestrings, pommes frites and diced potatoes (Matsuyama and Umeda, 1983). The pool-type irradiator installed with ^{60}Co source of 300 000 Ci has the capacity to treat 10 000 t of potatoes per month. Irradiation work usually commences in September/October when the fresh crop arrives and lasts until February. Potatoes of selected quality are irradiated in bulk in steel, wire netted containers (outside dimensions 1.7 m × 1.4 m × 1.1 m) holding 1.5 t of potatoes, to a minimum and maximum absorbed dose of 0.06 and 0.15 kGy. These containers move on a circular conveyor around the source and using a turn table, the containers are irradiated from both sides for uniform dose distribution. The irradiator has been in commercial operation since 1974 and an average of 15 000 to 22 000 t of potatoes have been irradiated annually. Irradiated potatoes are subsequently stored either in containers os in bulk under controlled temperatures depending on the end use. Potatoes to be sold as fresh table stock are bulk stored at 3° to 5°C using either mechanical refrigeration or by ventilating with the outside cold air depending on the season. Those potatoes to be processed are stored at 7°C. The irradiated potatoes are used from April onwards by which time the nonirradiated potatoes become unsuitable for processing. The processing qualities of the irradiated potatoes are reported to be excellent due to their low reducing sugar content. The irradiated potatoes are sold to the public either as fresh table stock or after processing into shoe strings, chips, and frozen french fries. It is reported that after potato irradiation came into operation in 1974, control of market price fluctuation in the Tokyo market has been attained successfully (Umeda, 1978, 1983). The total cost of this plant amounted to about US$ 1.3 million (1973 price, 1 US$ = 300 Japanese yen) and the cost of irradiation when the plant is operating at full capacity (3 months, 30 000 t) was estimated at US$ 7-10 per ton (Umeda, 1983). Details of the engineering aspects and the success and setback encountered in the commercial operation of this potato irradiator in Japan have been discussed (Umeda, 1975; 1978; 1983). The operational conditions for irradiation, curing, reconditioning and storage of potatoes depend much on the variety of the potato, but also on parameters such as cultivation of the crop, soil condition, and weather during harvest. The success of irradiation requires perfect treatment before and after irradiation, and appropriate storage conditions. Only sound potatoes should be irradiated; this requirement becomes very essential if irradiated potatoes are to be stored for more than six months (Umeda, 1983). Presently, all the 15 000 t of irradiated potatoes are sold in fresh market (T. Hayashi, personal communication).

In the former German Democratic Republic, substantial quantities of onions and smaller volumes of garlic were irradiated and marketed since 1983 (Anon., 1986; Dollstadt, 1984; Wetzel *et. al.*, 1985). The onions were irradiated in a new type of bulk cargo irradiator specially designed and constructed for this purpose (Dollstadt, 1984). However, the Unification Treaty of 1990 with the Federal Republic of Germany ended these activities and introduced in the former German Democratic Republic the general ban on food irradiation that existed in the Federal Republic of Germany (Diehl, 1995).

2.8. METHODS FOR DETECTION OF IRRADIATION TREATMENT

A reliable method for detection of irradiation treatment in bulbs and tubers would be advantageous in the regulation of national and international trade and to enforce labelling rules. A number of physical, chemical and biological methods are being developed for identification of irradiated onions and potatoes. Reviews on advances in the identification of irradiated foods are available in the published literature (Bogl, 1989; Delincee and Ehlermann, 1989; Schreiber *et al.*, 1993a; 1993b). The Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture has published a review of the current literature on analytical detection methods for irradiated foods (Anon., 1991) and is conducting a coordinated research programme on analytical detection methods.

2.8.1. Physical methods

2.8.1.1. Electrical conductivity and impedance measurements

Measuring the electrical conductivity was earlier suggested as a promising technique for identification of irradiated potatoes (Hayashi and Ehlermann, 1980; Scherz, 1970,1973; van Dongen *et al.*, 1973). Subsequent studies by Japanese researchers have shown that impedance measurement is a more reliable and practical technique for identification of irradiated potatoes (Hayashi and Kawashima, 1983b; Hayashi *et al.*, 1982, 1992, 1993). Impedance was measured by puncturing a potato tuber with a steel electrode and passing an alternating current through it. Although different types of electrode resulted in different values of the impedance parameters (magnitude, resistance, and reactance), the ratios of impedance parameters at 5 kHz to 50 kHz eliminated the influence of the type of electrodes. The impedance ratio at 5 kHz to 50 kHz (Z_{5k}/Z_{50k}) measured at 22° to 25°C at an apical region of potato tuber with 1 mA of alternating current resulted in the best identification of irradiated potatoes from unirradiated ones for up to 6 months (Hayashi *et al.*, 1992). Using this method 10 cultivars of potatoes irradiated at 0.1 kGy could be identified. The results were little influenced by the growing locality if the cultivar was the same (Hayashi *et al.*, 1993). Experiments with the Hungarian potato cultivar "Kisvardai Rozsa" confirmed the applicability of this technique; however, the ratio of phase angles ø15 k/ø80 k or ø 75 k/ø80 k provided statistically higher probability, and at least 3-times greater sensitivity than the earlier recommended parameter (Felfoldi *et al.*, 1993). This promising method, however, needs to be confirmed for more potato cultivars grown under varying agroclimatic conditions to corroborate the validity of the method.

2.8.1.2. Electron spin resonance spectroscopy

The electron spin resonance (ESR) spectroscopy is based on the detection of radical or paramagnetic centres formed in the food on irradiation. Since these centres tend to be unstable in tissues with high water content, the test is performed on skins with lower water content where the paramagnetic centres are stable for longer periods.

Measurement of the ESR spectra of the dry, outer skin of onion, red onion, garlic and shallot before and after irradiation at doses from 0.052 to 0.2 kGy showed increase in the intensity the of signal, which was one already present in nonirradiated items. However, with the absorbed dose the radiation-induced signal decayed with time (100 hours). It was, therefore, concluded that the outer skin of these foods are not suitable as a long-term post irradiation monitor (Desrosiers and McLaughlin, 1989, 1990).

2.8.1.3. Thermoluminescence

The thermoluminescence (TL) effect is based on electrons being transferred to an excited state by ionizing radiation and returning to a ground state emitting light when samples are heated, producing the typical glow curves. Compared to ESR, the TL effect is less influenced by water content and the TL intensity remains stable for longer periods.

Recent experiments have proved that irradiation with very low doses used to inhibit the sprouting of potatoes, onions and garlic can be clearly detected by TL analysis in routine control without the requirement for non-irradiated control samples for comparison (Schreiber *et al.*, 1993b). The TL effect was attributed to the minerals adhering to the bulbs and tubers. Since mineral contamination is so heavy in potatoes, onions and garlic, it is not difficult to separate identifiable mineral grains for analysis.If the soil where potatoes are grown contains feldspars, sprout inhibition treatment with 0.1 to 0.2 kGy doses can be detected for up to one year (Autio and Pinnioja, 1990).

2.8.2. Chemical and biochemical methods

Several methods based on changes in chemical and biochemical parameters have been suggested for the identification of irradiated potatoes. These include absorption spectra of thiobarbiturate derivatives present in water extracts (Winchester *et al.*, 1976a), chlorogenic acid content (Penner and Fromm, 1972), and phenylalanine ammonia lyase activity (Shirsat and Penner, 1973; Thomas *et al.*, 1978b). The measurement of enzyme activity or metabolites formed cannot be a reliable method because of the high biological variation among individuals of the same cultivar and the influence of the environment and storage duration on such changes.

Recently, flow cytometry (FCM) as a detection method for radiation-induced changes in DNA of onion meristem tissues, in combination with fluorescent dyes which bind specifically to double strand regions, has been examined (Selvan and Thomas, 1994). Nuclei from irradiated (0.06 to 0.09 kGy) onions showed a broader DNA distribution profile appearing as a wide coefficient of variation (cv; cv 4.78%) of the G_0/G_1 peak as compared to nonirradiated samples (cv, 2.39%). The DNA index (DI) of the diploid cells in control onions was 1 as against 0.74 in irradiated samples which, indicated the presence of G_0/G_1 cells with abnormal DNA content in the meristem tissue of irradiated onions. These differences were detected even after 150 days storage at ambient conditions. These results indicated the potential of the FCM technique for differentiating irradiated from nonirradiated bulbs.

2.8.3. Changes in histological and morphological characteristics

Histological and cytological methods seem to be more effective and reliable when performed under optimal conditions. Since irradiation at sprout-inhibiting dose levels irreversibly inhibits cell division and multiplication of not only the bud tissues but also the cells of parenchyma, the lack of cell division in tissue cultures (Sandret *et al.*, 1973) or formation of wound periderm (Matano *et al.*, 1972; Penner, 1970; Thomas, 1982) can be used as a reliable practical method for the identification of irradiated potatoes. This total and irreversible inhibition of cell division is not found in sprout inhibition treatments using chemical agents (Sandret *et al.*, 1973) at normal dose levels, although high dosages of MH and CIPC will also accomplish irreversible inhibition of cell division. Using potato tuber halves, it was demonstrated that the newly formed suberized cell layers in nonirradiated control tubers can be easily stripped off the wound surface after a 4 to 5 day wound healing period at 20° or 25°C and RH 90% while in irradiated tubers (0.05 kGy and above) this layer could not be removed easily (Thomas, 1982).

The lack of growth of buds after treatment with gibberellin, kinetin, triacontanol, or a mixture of gibberellin and ethrel can be used as a detection method for irradiated potatoes (Shimomura *et al.*, 1972a, 1972b, Thomas, 1993). In onions, the absence of rooting or the rate of root elongation when immersed in water provides a means for detection of irradiation treatment (Hori *et al.*,1964; Matin *et al*,. 1993; Munzner, 1976; Thomas,1993). The discoloration of inner buds of onions and garlic bulbs would be also helpful to detect the irradiation treatment.

Detection methods based on changes in histology and morphology of bulbs and tubers, however, requires a minimal duration of 4 to 5 days and as such will be of limited practical use when a quick test is needed at the international boundaries or by inspection agencies.

2.9. CONTROL OF THE PROCESS TO ENSURE PROPER PRACTICE

Details of Good Irradiation Practice for Sprout Inhibition of Bulbs and Tuber Crops have been published under the aegis of ICGFI (ICGFI, 1991a).

2.9.1. Pre-irradiation factors

The pre-irradiation factors are important aspects of the total process of preservation of bulbs and tubers by irradiation. Conditions influencing the storability of the tuber and bulb crops will also affect the results of irradiation treatment. Only cultivars/varieties of proven storage qualities are suitable for irradiation and long-term storage. Only products of good initial quality are suitable for irradiation. Irradiation cannot improve the storage properties of bulbs and tubers that are damaged or unhealthy at the time of treatment, which may even be detrimental in such cases. After the crops are harvested, they must be dried well, cleaned of adhering soil (especially potatoes) and sorted to remove badly damaged and infected material. Crops should not be harvested when the field is wet in order to avoid soil or mud adhering to them.

2.9.2. Commodity requirements

Onion bulbs should be of the quality required by local standards and be fully mature, sound, firm and well covered with dry scales and the fleshy edible scales should not be exposed. Bolted bulbs or bulbs with a thick neck should be avoided. Bulbs should be topped to 3 to 5 cm above the neck. Garlic bulbs should be mature and firm and heavy for their size. Bulbs which are light have either have lost moisture or have decayed and are unsuitable for irradiation. Proper curing (drying of the outer surface and neck) of the bulbs prior to irradiation is essential.

Potatoes that have been rained on should not be put into storage unless they are thoroughly dried. Washing may not be advisable, as often, if not properly dried and if necessary precautions are not taken to avoid the build-up of microbial contamination in the wash water, washing may lead to increased spoilage in storage. The stage of maturity of potatoes affects their susceptibility to damage and their subsequent storage characteristics. Mature tubers with fully developed periderms or well set skins only are suitable for irradiation and storage. Tubers must be cured properly after harvest, to allow healing of the wounds from harvesting and handling. This self-healing must occur before potatoes are irradiated since irradiation interferes with the natural healing process. Holding up to 30 days prior to irradiation, depending on the variety and the dormancy period, at 15° to 25°C and 90 to 95% RH maximizes healing. After curing potatoes should be handled in a manner so as to minimize damage.

Yams to be stored should be mature, firm and free from obvious defects. Harvest and handling damages must be allowed to heal prior to irradiation by holding the tubers under ambient conditions, generally, at temperatures as high as 35°C depending on the species and cultivar.

2.9.3. Containers and packaging

The packaging material in contact with the product should not undergo significant alteration of its functional properties nor yield toxic materials which can transfer to the product.

The size and shape of containers which may be used for irradiation, are determined in part by certain aspects of the irradiation facility. The critical aspects include the characteristics of the product, transport systems and of the irradiation source, as they relate to the dose distribution obtained within the container. The irradiation procedure will, therefore, be aided if the product packages are geometrically well defined and uniform. With certain irradiation facilities, it may be necessary to limit the use of certain package shapes and sizes.

Choice of packaging may be restricted by regulation in the country where the product is sold. Packaging materials used must comply with relevant national and local regulations (ICGFI is developing a list of packaging materials suitable for food irradiation).

Onions and garlic may be placed in bulk or pallet-sized boxes at the time of harvest and the same containers used for irradiation and storage to avoid damage to outer scales. Bags or sacks made of wide meshed jute or synthetic material are regarded as satisfactory containers.

In some instances the irradiation facility may have been built so as to require no containers for irradiation and, instead, to enable continuous irradiation of the crops as in the case of onions passing between radiation sources through gravity flow (Dollstadt, 1984; Krishnamurthy and Bongirwar, 1985).

In order to minimize the handling injuries to the potato tubers during and following irradiation treatment, the best possible approach is to use pallet boxes or bulk containers in which the product can be stored, dried, cured and irradiated. Under these conditions, the tubers are handled as little as possible and damage is reduced, which is essential for successful long-term storage. Post-irradiation storage can be either in the pallet box itself or in bulk, although in the latter case damage can again occur while unloading. The use of pallet boxes allows rapid mechanized handling and movement of the product with minimum injury. Pallet boxes can be stacked one over the other without increasing the load on tubers in the bottom layers.

Bags or sacks made of wide-meshed jute or synthetic material may be satisfactory containers for white potatoes. The use of such containers, however, may lead to damage to the potatoes unless very careful handling is employed. The process of filling potatoes into small boxes or containers, in which the potatoes are carried to the source for irradiation and then unloading from these boxes into the final storage container or bin, may result in damage and bruises. Such skin bruises may not heal during subsequent storage and may provide access for rot-causing bacteria and result in increased spoilage during storage. Similarly, the use of conveyors to move loose potatoes in layers past the radiation source also can increase surface injuries when the tubers drop from one belt to another or when they fall into containers or storage bins. This may increase spoilage during storage. However, modern agrotechnical practice of bulk handling and storage of potatoes, has developed suitable "soft handling" conveying mechanisms and these could be adapted, where necessary.

Although there has been no experience of irradiating yams in bulk containers, these tubers also require essentially the same type of handling during and following irradiation as in the case of potatoes. There is no experimental evidence on the wound-healing capacity of yams after irradiation. However, it can be presumed that irradiation may interfere with the tuber's ability to form a wound periderm. Therefore, it may be important to avoid injuries to the yam tubers during and following irradiation.

2.9.4. Pre-irradiation storage and transport

Precautions regarding avoidance or minimization of mechanical damage to bulb and tuber crops, must be maintained throughout any pre-irradiation storage (whether for curing purposes or for logistical reasons) and transport. As a rule, irradiation of tubers should be made as soon as the wound healing process has been completed which, in general, would be within one month after harvesting.

Onions must be irradiated to inhibit sprouting before the break of the dormancy period. The length of the dormancy period varies with the variety of onion and the holding temperature after harvest. In general, onions should not be held very long after harvest and before irradiation. Irradiation within one to two months after harvest may result in maximum sprout inhibition.

Temperature during storage should be chosen to prevent development of rot and browning of inner buds. In the case of bulbs, higher temperatures (e.g. 15°-20°C) at low relative humidities will be satisfactory, at the expense of somewhat increased weight loss.

During storage potatoes should be protected from light in order to prevent production of solanine, a toxic glycoalkaloid.

2.9.5. Post-irradiation storage and handling

Bulbs irradiated within the dormancy period at absorbed doses of 20 to 70 Gy can be stored at temperatures of 5°-20°C. Storage of irradiated onions at 0°-3°C to prevent discoloration of inner buds in some varieties, is not considered important for practical purposes. Air movement within storage bins or stacks is needed to remove respiration heat. Onions stored in open mesh bags or in slatted crates or pallet bins also require air circulation. Humidity levels below 50% cause faster desiccation; levels above 85% cause rotting. Onions can be stored for up to 8-9 months at ambient temperatures in moderate climatic conditions. In tropical countries storage at ambient temperatures for 4 to 5 months may be suitable provided the RH is 75 to 85%. Adequate ventilation must be provided. Garlic can be stored at intermediate temperatures (10°-11°C) and 85 to 90% RH, for 6 to 7 months. Losses during storage are due to microbial spoilage and desiccation.

Potatoes should be stored protected from light in order to prevent production of solanine, a toxic glyco-alkaloid. Since the wound healing process of potatoes is inactivated by irradiation, it is necessary to minimize handling injuries subsequent to irradiation. The best way to minimize such injuries is to use pallet boxes or bulk containers in which the potatoes can be stored, dried, cured, irradiated and again stored. This minimizes handling, therefore, handling damage. Air circulation within the container may be needed. Potatoes stored in bulk to heights of 4.5 m require good aeration to prevent rotting.

Although irradiation inhibits sprouting, it is important to store tubers under controlled temperature conditions to delay the growth of fungi and bacteria. Potatoes for sale as fresh table-stock may be stored at 3° to 5°C and 90% RH. Potatoes stored for preparing chips and French fries may be stored at 8° to 10°C and 90% RH. Storage at higher temperatures is necessary for the purpose of minimizing sugar build-up in the potato. In temperate climates proper storage temperatures may be secured by ventilation with cold outside air. In tropical climates, long-term storage of potatoes at ambient temperatures is not possible. For storage up to 6 months a temperature of 15°C may be employed. For longer storage periods a temperature of 10°C or lower is needed.

Yams may be stored for 4 to 5 months at temperatures of 25°-37°C and 50 to 85% RH in yam barns. In yam storage a vertical, or nearly vertical, wooden frame-work is used. The yams are tied to this frame-work individually with strings or ropes. Yams stored at 12°C or lower undergo physiological break-down. The optimum conditions for long term storage of yams are 16°C and 70% RH.

2.10. IRRADIATION PROCESS REQUIREMENTS

The Codex General Standard for Irradiated Foods (worldwide standard), Codex Stan 106-1983 (CAC/VOL XV-Ed 1) and the Recommended International Code of Practice for Operation of Irradiation Facilities Used for the Treatment of Food, CAC/RCP 19-1979. Rev. 1. (CAC/VOL XV-Ed 1) provide requirements and guidance regarding certain irradiation process parameters and irradiation facilities and their operation. It is recommended that these Codex reference be consulted and be followed.

In accordance with the Codex Standard, the ionizing radiation which may be employed in irradiating food is limited to:

(a) Gamma rays from the radionuclides ^{60}Co or ^{137}Cs.
(b) X-rays generated from machine sources operated at or below energy level of 5 MeV.
(c) Electrons generated from machine sources operated at or below an energy level of 10 MeV.

It should be noted that irradiation by electrons, having limited energy penetration, is not possible for packages or products moving in layers exceeding certain thickness.

It is not possible to distinguish irradiated from nonirradiated product by inspection, and, therefore, it is important that, in the operation of an irradiation facility appropriate means, such as physical barriers, be employed for keeping the irradiated and non-irradiated product separate.

Indicators which change color or which otherwise undergo some easily determined and time-stable change when exposed to radiation at the dose required, are still under development. Such devices, common in the radiation-sterilization industry, used as a paper sticker, or equivalent, and attached to each product unit, such as a carton, could assist the operator in identifying irradiated product.

It is important that adequate records of the operation of the irradiation facility be kept, and the products which have been irradiated should be identified by lot numbers or by other suitable means. Such measures to enable verification of the irradiation treatment are likely to be required by government regulatory agencies.

2.10.1. Recommended dose ranges

General: Of the irradiation process parameters, the most important is the amount of ionizing energy absorbed by the product. This is termed as the "absorbed dose". The unit of absorbed dose is the Gray (Gy). One Gy is equal to the absorption of one joule of energy per kg material. It is important that the products receive the minimum absorbed dose required to achieve the desired effect and that the uniformity ratio be maintained at an appropriate level. This requires through dose mapping.

Dose for bulbs: Onions and garlic

As already stated in Section 2.3 the absorbed dose required to prevent onions from sprouting is highly dependent on growing conditions, varietal differences, dormancy state of bulbs, curing conditions, and post-irradiation storage temperature. Generally speaking, the absorbed dose needed for satisfactory sprout inhibition may range from 0.02 to 0.15 kGy depending on the above factors and on the influence brought about by the interaction among these factors. Absorbed doses of 0.02 to 0.07 kGy are effective if irradiation is carried out within 1-2 months after harvest.

As with onions, the absorbed dose required for satisfactory sprout inhibition of garlic is dependent upon the time of irradiation after harvest. Absorbed doses in the range of 0.02 to 0.06 kGy, if applied shortly after harvest, are effective. If the garlic is irradiated at later periods after harvest, absorbed doses of 0.1 to 0.15 kGy may be needed.

Dose for tubers: potatoes and yams

The optimum absorbed dose for sprout inhibition of white potatoes varies with the varieties, time of irradiation after harvest and post irradiation storage temperature. For many varieties a dose of 0.07 to 0.1 kGy is effective. It is necessary, however, to determine the exact absorbed dose needed for the particular variety. Processing of bulk quantities in large containers will result in a wide dose distribution. Attention should be paid to the effects of the resulting maximum dose.

Dosimetry: The radiation dose absorbed by the product and the dose uniformity or distribution within the product package are dependent on many factors. These factors include the nature of the source, the activity of the source, the geometry of the source, the geometry of the conveyer, the density of the product, the nature of packaging and its dimensions, and the distribution of the packages in the carrier.

The control of the irradiation procedure so as to deliver a prescribed dose entails a number of considerations, important among which is the technology for measuring dose, which is termed dosimetry. It is recommended that manuals on dosimetry procedures be consulted (see ASTM Standard E 1204; ASTM Standard E 1261; (Chadwick *et al.*, 1977; McLaughlin *et al.*, 1989).

2.11. LABELLING REQUIREMENTS

The Codex General Standard for Irradiated Foods (Anon., 1984) states:

"6.1. *Inventory control*
For irradiated foods, whether prepackaged or not, the relevant shipping documents shall give appropriate information to identify the registered facility which has irradiated the food, the date(s) of treatment and lot identification.

6.2. *Prepackaged foods intended for direct consumption*
The labeling of prepackaged irradiated foods shall be in accordance with the relevant provisions of the Codex General Standard for the Labelling of Prepackaged Foods.

6.3. *Foods in bulk containers*
The declaration of the fact of irradiation shall be made clear on the relevant shipping documents."

For pre-packaged foods intended for direct consumption the requirements are described in the Codex General Standard for the Labelling of Prepackaged Foods (Codex, 1989). While foods treated by other physical preservation processes such as heating, refrigeration or freezing are not required to be labelled that they are so treated, the Codex General Standard for the Labelling of Prepackaged Food, as amended by the 19th Session of the Codex Alimentarius Commission, states that:

"5.2.1. The label of a food which has been treated with ionizing radiation shall carry a written statement indicating that treatment in close proximity to the name of the food. The use of the international food irradiation symbol, as shown below, is optional, but when used it shall be in close proximity to the name of the food.

When an irradiated product is used as an ingredient in another food, this shall be so declared in the list of ingredients. 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."

Labelling of minor ingredient and second generation products produced with irradiated ingredients is a complicated and controversial issue (Ladomery and Nocera, 1980), and views of governments vary significantly from no labelling of "second generation irradiated food" in the USA, to labelling of all irradiated ingredients in the food in the case of Denmark. A survey of national regulations, including labelling, has been prepared under the aegis of ICGFI (ICGFI, 1991b).

3. WHOLESOMENESS DATA

Wholesomeness implies satisfactory nutritional quality with toxicological and microbiological safety for consumers. Many countries have legal requirements for satisfactory evidence of the safety of irradiated foods for human consumption and an enormous research effort has been directed towards wholesomeness testing of irradiated foods. This has involved multigeneration animal feeding trials followed by reproduction, biochemical, clinical, hematological and histopathological studies to test for abnormalities arising from toxic, carcinogenic, mutagenic or teratogenic effects of feeding irradiated foods under standard testing protocols. The safety and wholesomeness of irradiated foods has been critically examined in a recent publication (Diehl, 1990).

It is pertinent to point out that, based on the results of chemical, nutritional, microbiological and wholesomeness studies, irradiated potato was one of the food commodities unconditionally cleared for human consumption by a Joint FAO/IAEA/WHO Expert Committee (JECFI) in 1977 (WHO, 1977). The same committee accorded provisional acceptance of irradiated onions and suggested further multigeneration reproduction study in rats at feeding levels below that causing biological changes due to the biologically active substances naturally present. The subsequent JECFI Report on "Wholesomeness of Irradiated Food" concluded that irradiation of any food commodity up to an overall average dose of 10 kGy presents no toxicological hazard and introduces no nutritional or microbiological problems (WHO, 1981).

Specific toxicological investigations on irradiated onions included short-term and long-term feeding studies in mice, rats, beagle dogs and pigs (Aravindakshan *et al.*, 1981a, 1981b; Chaubey and Chauhan, 1981; Gabriel and Edmonds, 1966; 1976a; 1976b; Hillard, 1974; Hillard *et al.*, 1966; Ikeda, 1975; Kraybill, 1969; Oliver *et al.*, 1966; Rust, 1969b; Van Petten, 1974; Van Petten *et al.*, 1966a; 1966b) while investigations on irradiated potatoes included short-term and long-term feeding studies in mice, rats, dogs, rhesus monkeys and pigs (Bernardes and De Oliviera, 1974; Bernardes *et al.*, 1972; Brownell *et al.*, 1959; Burns *et al.*, 1960; Coquet *et al.*,1972,1973,1974; Horne and Hickmann, 1959; Ikeda, 1975; Jaarma and Bengtsson, 1966; Jaarma and Henrickson, 1964; Jaarma *et al.*, 1966; Kline *et al.*, 1960; McCay and Rumsey, 1961; Palmer *et al.*, 1972; 1973; 1975; Prochazka and Cerna, 1961; Rust, 1969a; Sialy *et al.*, 1976; Teply *et al.*, 1959; Wolf, 1974). A compilation of bioassay data on the wholesomeness of irradiated food items (Barna, 1979) has listed 30 references in which irradiated onions constituted part of the diet and 81 references in which irradiated potatoes formed part of the diet fed to mice, rats, dogs, monkeys and pigs.

The parameters examined in the onion feeding studies included the following: Food consumption, protein quality, digestibility of fat and carbohydrate, food efficiency, water intake, growth, body weight, weight gain, state of health, physical condition, appearance, behavior, mortality of adults, gross pathology, histopathology, incidence of tumor, hematological status, RBC, WBC, differential WBC, haemoglobin content, hematocrit value, blood chemistry, serum bilirubin level, serum glutamic-pyruvate transaminase, cholinesterase, clinical chemistry, urine analysis, enzyme activities in liver, cholinesterase in liver, glutamic-oxaloacetic transaminase in intestinal mucosa, reproductive performance, osmotic resistance and activity of spermatozoids, fertility, mating rate, number of implantations, frequency in parturitions, number of young at parturition, foetal mortality, litter size, weight of pups per litter at weaning, survival to weaning, mutagenicity, studies employing dominant lethal assay and micronucleus test, and, teratogenic effects.

The potato feeding studies, in addition to the above listed, examined the following parameters: Biological value, digestibility, protein digestibility, protein and net protein utilization, N-balance, appetite, acceptability, life span, growth rate, longitudinal growth of bones, mother weight, vaginal cytology, spermatogenesis, chromosome analysis in spermatogonia, weight of embryos, embryonal lethality, number of viable embryos, living:dead embryo rate, length of oestrus cycles, number of corpora lutea, preimplantation loss, post-implantation loss, length of gestation, resorption in uterus, number of young at parturition, foetal mortality, still birth ratio, litter number at birth, sex ratio, lactation performance, reticulocyte number, volume of blood, prothrombin time, specific gravity of plasma, blood sugar level, glucose tolerance curve, serum total protein content, albumin/globulin quotient, non-protein nitrogen, rest-nitrogen level, blood urea-nitrogen, cholesterin level, hormones (oestrogen, pregnadiol) in urine, organs function, phosphorylation in mitochondria in liver, liver composition (lipid, phospholipid, fatty acids, total protein), enzyme activities in liver (ornithine-carbamyl transferase, glutamic-oxalacetic transaminase, glutamic-pyruvate transminase, butyril cholinesterase, succinate dehydrogenase), enzyme activities in serum (unchanged catalase, ornithine-carbamyl transferase, serum glutamic oxaloacetic transminase, serum butyril cholinesterase), gross pathology of reproductive organs, histopathology of reproductive organs, type of tumor, and time of tumor detection.

In earlier studies researchers from Soviet Union has reported the formation of radiotoxins in irradiated potatoes which showed cytotoxic and mutagenic effects in mice (Kuzin and Yurov, 1968; Kuzin *et al.*, 1975). It was claimed that alcoholic extracts of freshly irradiated potatoes containing these radiotoxins induced dominant lethal mutations in mice (Kopylov, 1977; Kopylov *et al.*, 1958). However, later studies of several groups failed to replicate the findings reported by the Soviet authors. A dominant lethal test in mice carried out by Canadian workers (Levinsky and Wilson, 1975), a micronucleus test in rats reported from Germany (Hossain *et al.*,1976) and *in vivo* tests conducted in Japan (Ishidate *et al.*, 1981) failed to show mutagenic effects of extracts of freshly irradiated potatoes. Since further work caried out by Soviet authors (Zajcev et al., 1975) also failed to confirm the earlier reports it must be concluded that the original findings (Kopylov *et al.*, 1958) was artefactual (Diehl, 1995).

The results of the wholesomeness data on irradiated onions and potatoes have been summarized in the 1970, 1977 and 1981 Reports of Joint FAO/IAEA/WHO Expert Committee (WHO, 1970; 1977; 1981).

4. NATIONAL AND INTERNATIONAL CLEARANCES

Clearances issued at national level for irradiated potato, onions garlic and shallot are listed in Tables 1 to 4, respectively. It can be seen that 28 countries have granted unconditional clearances for potatoes (Table 1), 27 countries have granted unconditional clearance for onions (Table 2), 17 countries have granted unconditional clearances for garlic (Table 3), and, 4 countries have granted unconditional clearances for shallots (Table 4).

The ICGFI has recently prepared a comprehensive review on current national laws and regulations on food irradiation (ICGFI, 1990).

Table 1

List of Clearances - Irradiation of Potatoes (Dose in kGy)

02-Sep-96

COUNTRY	PURPOSE	TYPE OF CLEARANCE	DATE OF CLEARANCE	DOSE MIN	DOSE MAX
ARGENTINA	SPROUT INHIBITION	UNCONDITIONAL	03/04/87	0.03	0.15
BANGLADESH	SPROUT INHIBITION	UNCONDITIONAL	29/12/83	0	0.15
BELGIUM	SPROUT INHIBITION	CONDITIONAL	16/07/80	0	0.15
BRAZIL	SPROUT INHIBITION	UNCONDITIONAL	08/03/85	0	0.15
CANADA	SPROUT INHIBITION	UNCONDITIONAL	09/11/60	0	0.15
CHILE	SPROUT INHIBITION	UNCONDITIONAL	29/12/82	0	0.15
CHINA	SPROUT INHIBITION	UNCONDITIONAL	30/11/84	0	0.2
COSTA RICA	SPROUT INHIBITION	UNCONDITIONAL	07/07/94	0	0.15
CROATIA	SPROUT INHIBITION	UNCONDITIONAL	21/06/94	0	0.5
CUBA	SPROUT INHIBITION	UNCONDITIONAL	01/04/87	0	0.1
HUNGARY	SPROUT INHIBITION	CONDITIONAL	28/01/83		0.1
INDIA	SPROUT INHIBITION	UNCONDITIONAL	09/08/94	0	0.15
INDONESIA	SPROUT INHIBITION	UNCONDITIONAL	29/12/87	0	1
ITALY	SPROUT INHIBITION	UNCONDITIONAL	30/08/73	0	0.15
JAPAN	SPROUT INHIBITION	UNCONDITIONAL	30/08/72	0	0.15
KOREA, REP. OF	SPROUT INHIBITION	UNCONDITIONAL	28/09/87	0	0.15
MEXICO	SPROUT INHIBITION	UNCONDITIONAL	07/04/95	0	0.2
PAKISTAN	SPROUT INHIBITION	UNCONDITIONAL	13/06/88	0	0.15
RUSSIAN FEDERATION	SPROUT INHIBITION	UNCONDITIONAL	17/07/73	0	0.3
SOUTH AFRICA	SPROUT INHIBITION	CONDITIONAL	06/02/87	0.15	10
SPAIN	SPROUT INHIBITION	UNCONDITIONAL	04/11/69	0.05	0.15
SYRIA	SPROUT INHIBITION	UNCONDITIONAL	02/08/86	0	0.15
THAILAND	SPROUT INHIBITION	UNCONDITIONAL	04/12/86	0	0.15
UKRAINE	SPROUT INHIBITION	UNCONDITIONAL	17/07/73	0	0.3
URUGUAY	SPROUT INHIBITION	UNCONDITIONAL	23/06/70		0.15
VIET NAM	SPROUT INHIBITION	CONDITIONAL	03/11/89	0	0.15
YUGOSLAVIA	SPROUT INHIBITION	UNCONDITIONAL	17/12/84	0	10

Note: There are countries that do not approve specific products for irradiation, but instead, approve irradiation of groups or classes of foods, such as Tubers (includes Potatoes) and Bulbs (includes Onions, Garlic) (see notes Tables 5 and 6).

Table 2

List of Clearances - Irradiation of Onions (Dose in kGy) *02-Sep-96*

COUNTRY	PURPOSE	TYPE OF CLEARANCE	DATE OF CLEARANCE	DOSE MIN	DOSE MAX
ARGENTINA	SPROUT INHIBITION	UNCONDITIONAL	03/04/87	0.02	0.15
BANGLADESH	SPROUT INHIBITION	UNCONDITIONAL	29/12/83	0	0.15
BELGIUM	SPROUT INHIBITION	CONDITIONAL	16/10/80	0	0.15
BRAZIL	SPROUT INHIBITION	UNCONDITIONAL	08/03/85	0	0.15
CANADA	SPROUT INHIBITION	UNCONDITIONAL	25/03/65	0	0.15
CHILE	SPROUT INHIBITION	UNCONDITIONAL	29/12/82	0	0.15
CHINA	SPROUT INHIBITION	UNCONDITIONAL	30/11/84	0	0.15
COSTA RICA	SPROUT INHIBITION	UNCONDITIONAL	07/07/94	0	0.15
CROATIA	SPROUT INHIBITION	UNCONDITIONAL	21/06/94	0	0.5
CUBA	SPROUT INHIBITION	UNCONDITIONAL	01/04/87	0	0.06
FRANCE	SPROUT INHIBITION	UNCONDITIONAL	12/07/84	0.075	0.15
HUNGARY	SPROUT INHIBITION	UNCONDITIONAL	23/06/82	0.05	0.2
INDIA	SPROUT INHIBITION	UNCONDITIONAL	09/08/94	0.03	0.09
INDONESIA	SPROUT INHIBITION	UNCONDITIONAL	29/12/87	0	1
ITALY	SPROUT INHIBITION	UNCONDITIONAL	30/08/73	0.075	0.15
KOREA, REP. OF	SPROUT INHIBITION	UNCONDITIONAL	16/10/87	0	0.15
MEXICO	SPROUT INHIBITION	UNCONDITIONAL	07/04/95	0	0.2
PAKISTAN	SPROUT INHIBITION	UNCONDITIONAL	13/06/88		0.15
PHILIPPINES	SPROUT INHIBITION	CONDITIONAL	26/10/81	0.05	0.1
POLAND	SPROUT INHIBITION	UNCONDITIONAL	01/04/87		0.06
RUSSIAN FEDERATION	SPROUT INHIBITION	UNCONDITIONAL	17/07/73	0	0.06
SOUTH AFRICA	SPROUT INHIBITION	CONDITIONAL	19/03/91	0.15	10
SPAIN	SPROUT INHIBITION	UNCONDITIONAL	10/09/75	0	0.08
SYRIA	SPROUT INHIBITION	UNCONDITIONAL	02/08/86	0	0.15
THAILAND	SPROUT INHIBITION	UNCONDITIONAL	04/12/86	0	0.15
UKRAINE	SPROUT INHIBITION	UNCONDITIONAL	17/07/73	0	0.06
VIET NAM	SPROUT INHIBITION	CONDITIONAL	03/11/89	0	0.1
YUGOSLAVIA	SPROUT INHIBITION	UNCONDITIONAL	17/12/84	0	10

NOTE: There are countries that do not approve specific products for irradiation, but instead, approve irradiation of groups or classes of foods, such as Tubers (includes Potatoes) and Bulbs (includes Onions, Garlic) (see notes Tables 5 and 6).

Table 3

List of Clearances - Irradiation of Garlic (Dose in kGy) *02-Sep-96*

COUNTRY	PURPOSE	TYPE OF CLEARANCE	DATE OF CLEARANCE	DOSE MIN	DOSE MAX
ARGENTINA	SPROUT INHIBITION	UNCONDITIONAL	03/04/87	0.02	0.15
BELGIUM	SPROUT INHIBITION	CONDITIONAL	16/10/80	0	0.15
CHINA	SPROUT INHIBITION	UNCONDITIONAL	30/11/84	0	0.1
CROATIA	SPROUT INHIBITION	UNCONDITIONAL	21/06/94	0	0.5
CUBA	SPROUT INHIBITION	UNCONDITIONAL	01/04/87	0	0.08
FRANCE	SPROUT INHIBITION	UNCONDITIONAL	12/07/84	0.075	0.15
INDONESIA	SPROUT INHIBITION	UNCONDITIONAL	29/12/87	0	1
ITALY	SPROUT INHIBITION	UNCONDITIONAL	30/08/73	0	0.15
KOREA, REP. OF	SPROUT INHIBITION	UNCONDITIONAL	14/12/91	0	0.15
MEXICO	SPROUT INHIBITION	UNCONDITIONAL	07/04/95	0	0.2
PAKISTAN	SPROUT INHIBITION	UNCONDITIONAL	13/06/88	0	0.15
PHILIPPINES	SPROUT INHIBITION	CONDITIONAL	26/10/81	0.05	0.1
POLAND	SPROUT INHIBITION	UNCONDITIONAL	01/10/90		0.15
THAILAND	SPROUT INHIBITION	UNCONDITIONAL	04/12/86	0	0.15
VIET NAM	SPROUT INHIBITION	CONDITIONAL	03/11/89	0	0.1
YUGOSLAVIA	SPROUT INHIBITION	UNCONDITIONAL	17/12/84	0	10

Note: There are countries that do not approve specific products for irradiation, but instead, approve irradiation of groups or classes of foods, such as Tubers (includes Potatoes) and Bulbs (includes Onions, Garlic) (see notes Tables 5 and 6).

Table 4

List of Clearances - Irradiation of Shallots

02-Sep-96

(Dose in kGy)

COUNTRY	PURPOSE	TYPE OF CLEARANCE	DATE OF CLEARANCE	DOSE MIN	DOSE MAX
BELGIUM	SPROUT INHIBITION	CONDITIONAL	16/10/80	0	0.15
FRANCE	SPROUT INHIBITION	UNCONDITIONAL	12/07/84	0.075	0.15

Note: There are countries that do not approve specific products for irradiation, but instead, approve irradiation of groups or classes of foods, such as Tubers (includes Potatoes) and Bulbs (includes Onions, Garlic) (see notes Tables 5 and 6).

Table 5

List of Clearances - Irradiation of Bulbs (Dose in kGy)

02-Sep-96

COUNTRY	PURPOSE	TYPE OF CLEARANCE	DATE OF CLEARAN	DOSE MIN	DOSE MAX
INDONESIA	SPROUT INHIBITION	UNCONDITIONAL	29/12/87	0	0.15
MEXICO	SPROUT INHIBITION	UNCONDITIONAL	07/04/95	0	0.2

Note:

1) There are countries that do not approve specific products for irradiation, but instead, approve irradiation of groups or classes of foods, such as Tubers (including Potatoes) and Bulbs (including Onions, Garlic).

2) The U.K. includes Bulbs and Tubers under its clearance for "Vegetables" (01/01/91, dose max 1 kGy).

3) The USA includes Bulbs and Tubers under "growth and maturation inhibition of fresh foods" (18/04/86, dose max 1 kGy).

4) Israel now includes Bulbs and Tubers under its clearance for "Vegetables" (17/02/87), dose max 1 kGy).

Table 6

List of Clearances - Irradiation of Tubers (Dose in kGy)

02-Sep-96

COUNTRY	PURPOSE	TYPE OF CLEARANCE	DATE OF CLEARANCE	DOSE MIN	DOSE MAX
CROATIA	SPROUT INHIBITION	UNCONDITIONAL	21/06/94	0	0.5

Note:

1) There are countries that do not approve specific products for irradiation, but instead, approve irradiation of groups or classes of foods, such as Tubers (including Potatoes) and Bulbs (including Onions, Garlic).

2) The U.K. includes Bulbs and Tubers under its clearance for "Vegetables" (01/01/91, dose max 1 kGy).

3) The USA includes Bulbs and Tubers under "growth and maturation inhibition of fresh foods" (18/04/86, dose max 1 kGy).

4) Israel now includes Bulbs and Tubers under its clearance for "Vegetables" (17/02/87, dose max 1 kGy).

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Annex 1

Survey of studies on sprout inhibition of potatoes by irradiation in various countries

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Reference
Algeria					
Ostara, Desiree	0.08	4°, 10°, RT 80-90%		4 months	Nouami *et al.*, 1987
Argentina					
Hunical, Kennebec	0.03-0.25	RT	2-3 months	9 months	Pahissa *et al.*, 1972
Australia					
Kennebec, Up-to-date, Sebago, Sequoia	0.05-0.16	7.2°, 20°	10 weeks	6 months	Wills, 1965a
Bangladesh					
Burma, Deshi, Ultimus	0.08-0.10	RT; 12°	4-6 weeks	8-9 months	Chowdhury & Rahman, 1973 Hossain *et al.*, 1984-85 Siddique *et al.*, 1973
Belgium					
Bintje, Climax, Dore, Ersterling, Electre, Gari, Gaumaise, Pimpernal, Saskia	0.08-0.20	4°, 7 - 12° 15°, 18 - 20° 7 - 8°, 8 - 10°, 8 - 20°			Schietecatte & Nyes, 1975
Bulgaria					
Early crop, Middle-early crop, Late crop	0.08-0.10			1 year	Vylchev, 1972

Annex 1 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Reference
Canada					
Katahdin, Netted Gem, Katahdin, Russet Burbank and other ten varieties	0.08 - 0.16	4.4° and 20° 12.8°		11 months 8 months	Anon. 1960, 1962b, 1962b; Errington & MacQueen, 1961
Cherokee, Irish Cobbler, Katahdin, Kennebec, Netted Gem, Sebago	0.08	Up to 26.7° 12.8°		Up to 10 months	Anon., 1963b
Czechoslovakia					
Blanik, Radka, Nora, Eba	0.06 - 0.15	10 - 12° 65%; 3 - 10°, 65 - 95%	6 weeks	7 months	Salkova *et al.*, 1978
Chile					
Ackersegen, Arka, Desiree, Spartaan Ultimus, Urgenta	0.10	6 - 10° 80 - 85%	3 - 4 months	3½ months	Cruz, 1977
Colombia					
Pardo Pastusa, Toccarena	0.05 - 0.15	10°		8 months	Perdeno *et al.*, 1964
Various	0.08 - 0.10			7 - 8 months	Sanin-Sader, 1966

Annex 1 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Reference
Denmark					
Bintje	0.06 - 0.12 (0.08)	5,10 and 15°	1,2,4,6 months	8 months	Truelsen, 1960
Egypt					
Alpha,King Edward	0.06 - 0.14	11 - 29°	3 months	1 year	Roushdy *et al.*, 1973
Alpha	0.08 - 0.14	30 - 35°	2 weeks	6 months	Zidan, 1968
France					
Saskia,Bintje	0.05 - 0.15 (0.075 - 0.10)			12 months	Vidal, 1959
Bintje,Kerpondy		10 - 12°		1,5 years	Sandret & Michiels, 1966
German Democratic Republic					
Amsel,Apollo,Drossel, Frink,Gerlinde, Gunosa,Kastor Li.4987/54,Meise, Ora,Pirat,Pollux, Rot Kehlchen,Sagitta, Schwalhe,Spatz, Spekula,Sperber, Stieglitz	0.04 - 0.16 (0.08)	4 - 18°		15 months	Buhr *et al.*, 1967

Annex 1 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Reference
Germany, Federal Rep. of					
Ackersegen,Bona,Vera	0.025 - 0.16 (0.08)	2 - 14°			Patzold and Kolb, 1957
Corona,Feldeslohn	0.04				Gantzer & Heilinger, 1964
Heida	0.01 - 0.60			30 weeks	Berger and Wolf, 1965
Anco,Arensa, Bona, Carmen,Cosima, Datura,Delos, Feideslohn,Grata, Heida,Hako,Isola, Lori,Maritta,	0.04 - 0.15	15°		11 weeks	Hansen & Grunewald,1964
Bona,Heida	0.05 - 0.15	15°; 85%			Berger and Hansen, 1962
Saturna,Tasso	0.08 and 0.15			7 months	Penner *et al.*, 1972a
India					
Gola,Up-to-date	0.03 - 0.09		2 weeks	4 months	Mathur, 1963a
Phulwa	0.06	12°;85 - 90% 21 - 35°; 57 - 90%		10 months 5 months	Lewis and Mathur, 1963
Phulwa,Up-to-date	0.06	RT (21 -35°) 10 - 12°		1.5 months	Dharkar, 1966

Annex 1 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Reference
India (cont.)					
Up-to-date	0.035	9°;85 - 90%	Up to 16 weeks	Up to 44 weeks	Mathur, 1963b
Gola, Up-to-date, Kufri Alankar, Kufri Chandramukhi, Kufri Jyoti, Kufri Kuber, Kufri Sheetman, Kufri Sindhuri, SLB/Z-405(a) Kufri Badshah	0.10 - 0.14 (0.10)	RT (27-32°) 60 - 80% 20°;80 - 85% 15°;80 - 85% 10°;85 - 90%	1 - 2 months	Up to 4½ months Up to 6 months Up to 9 months Up to 9 months	Thomas, 1979; Thomas *et al.*, 1978a; Thomas *et al.*, 1978b; Shirsat *et al.*, 1991;
Iran, Islamic Rep. of					
Alpha, Baraca Pashandi	0.05 - 0.15		2½ months	9 months	Sekhavat *et al.*, 1978
Israel					
Up-to-date	0.06 - 0.14	RT 4,8 and 14°	8 weeks	Up to 12 months	Kahan & Temkin - Goroderski, 1968
Italy					
Bintje	0.085 and 0.10	10°;85 - 90%		10 months	Baraldi *et al.*, 1971a

Annex 1 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Reference
Japan					
Danshaku	0.04 - 0.07 (0.06)	RT (1 - 24°) and 4°		8 months	Kume *et al.*, 1976
Irish Cobbler	0.03 - 0.12	RT			Ogata *et al.*, 1959a
May Queen, Norin-I-go	0.07 - 0.15 (0.07)	5°, 10°	40 days	8 months	Takano *et al.*, 1972b
Danshaku, May Queen Norin Ichigo, Yukishiro	0.10	RT and 5°	20 days	Up to 7 months	Takano *et al.*, 1974a
Norin-I-go	0.07	RT and 5°		Up to 8 months	Umeda *et al.*, 1969a
Danshaku, Shimabara	0.07 - 0.30 (0.07)	1° and 5°		Up to 8 months	Umeda *et al.*, 1969b
Korea, Rep. of					
Irish Cobbler, Kennebec, Saco, Shimbara, Tachibana,	0.04 - 0.09 (0.06)	Low, High 24° and 4°	1 week		Park *et al.*, 1967
Warba	0.03 - 0.12	RT			
Netherlands					
Bintje, Saturna		9°; 90 - 95%			Buitelaar, 1970
New Zealand					
Chippewa, Itham, Hardy	0.07 - 0.20	21.1°	6 months	10 weeks	McNaughton, 1960

Annex 1 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Reference
Norway					
Unspecified	0.05 - 0.40 (0.10)	4 - 6°		12 months	Mikaelsen and Roer, 1956
Kerr's Pink	0.05 - 0.15	7 - 14°		15 months	Mikaelsen *et al.*, 1958
Pakistan					
Holland,Ultimas	0.02 - 0.10	28.3°;69%	15 days	210 days	Farooqi *et al.*, 1967
Desire,Ultimas	(0.10)	RT (25 -40°) 40 - 50% and 14-16°; 60-70%		8 months	Khan and Wahid, 1978
Philippines					
Unspecified	0.05 - 0.20		1 month	8 months	Gonzales, 1975
Portugal					
Arran Banner	0.05 - 0.15	18 - 20°; 70 - 80%			Teixeira&Baptista, 1968
Anco, Arran Banner, Arran Consul,Claudia, Condea, Desiree	0.10			4 months	
South Africa					
BPI, Up-to-date, Pimpernel	Up to 0.15			16 weeks	Winchester *et al.*, 1976b

Annex 1 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Reference
Spain					
Alava, Gineke	0.05 - 0.15	10 - 25°; 40 - 87%		9 months	Garcia de Matoes *et al.*, 1969
Alava, Gineke, Urgenta	0.05	19 - 31° 60 - 80%		150 days	Fernandez and Gonzalez, 1969
Sweden					
Bintje, Eva, President	0.16	5°			Jaarma, 1958
Bintje, Early Puritan, Eva, President, Primula, Ulster Chieftian	0.10 - 0.20		1 month		Jaarma, 1969b
Turkey					
Alpha, Ari, Cosima, Ostara, Primabel, Resyent, Sarikiz	0.01 - 0.25	15°; 65%		8 months	Anon., 1976
United Kingdom					
Dr. McIntosh	0.02 - 0.35	10°; 78%	5 days, 55 days, 6 months	15 months	Burton and Hannan, 1957
Arran Counsul, Craigs Defiance, Golden Wonder, Home Guard	0.085	10°; 78%	3 - 4.5 months	15 months	Burton and Hannan, 1957 Burton and de Jong, 1959

Annex 1 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Reference
USA					
Green Mountain	0.0125 - 0.40 (0.10)	4.4 - 21°; 30 - 40%		6 months	Sawyer and Dallyn, 1955
Green Mountain Katahdin	0.025 - 0.12 (0.10)	4.4,10 and 21.1°		10 months	Sawyer and Dallyn, 1956
Cobbler,Green Mountain Katahdin,Kennebec, Russet Burbank, Saco	0.05 - 0.20	10 and 21.1°		8 months	Sawyer and Dallyn, 1961
Russet Rural,Sebago	0.05 - 2.0 (0.10 - 0.15)	13 and 22°; 85 - 90%			Heiligman, 1957
Katahdin,Russet Burbak,Russet Rural, Sebago	0.05 - 2.0 (0.10)	1.7 - 26.7°; 60 - 90%		5 months	Brownell *et al.*, 1957b
Katahdin,Red Pontiac, Russet Burbank, White Sebago	0.05 - 0.15	5,8,3,and 12.8°	1,2,or 3 months	2 years	Ellis *et al.*, 1959 Workman *et al.*, 1960
Russet Burbank	0.05 - 0.8 (0.10)	RT, 3.3, 10 and 21°	2 week intervals up to 34 weeks	333 days	Sparks and Iritani, 1964
Russet Burbank	0.062 - 0.15 (0.10)	RT, 2.2, and 7.2°	2 days	182 - 211 days	Bradley, 1968

Annex 1 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Reference
Uruguay					
Kennebec	0.08 - 0.10			8 months	Merino, 1978
USSR					
Lorkh	0.10			1 year	Metlitsky *et al.*, 1957
Berlikhingen	0.10 and 0.40			8 months	Rakitin & Kryolov, 1957
Berlikhingen, Epron, Lorkh,Moskovski, Peredovik,Priekul'skÜ, Rannyaya roza,Seyanets, 9729/Ukh Tomsku	0.02 - 0.10	Various		12 months	Rubin *et al.*, 1959
Lorkh	0.05 - 0.15		2 weeks, 5 months, 7 months	13 months	Metlitsky *et al.*, 1968
Venezuela					
Katahdin	0.0125 - 0.20	10 - 22°; 65 - 95%	15 days	8 months	Solanas and Darder, 1968

Annex 2

Survey of studies on sprout inhibition of onions by irradiation in various countries

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Remarks	Reference
Argentina						
Valenciana, Sintetica 14	0.03	6-32°,50-90%	40 days	4 months	Complete sprout inhibition	Curzio & Croci,1983
Bangladesh						
Unspecified	0.02-0.10	RT		8 months	Complete sprout inhibition at 0.06-0.08 kGy	Chowdhury & Rahman,1973 Matin *et al.*, 1985,1988, 1990
Unspecified	0.05-0.07	RT(25-32°), 70-90%; 15.6-18.3°;10-15°;4°		8 months		Hossain *et al.*,1982
Brazil						
Unspecified	0.08-0.16	5-10°				Zonenschain, 1975
Canada						
Brigham Yellow Globe,Autum spice,Sweet Spanish	0.032-0.095	Up to 26.7°		300 days	Good sprout inhibition when irradiated within 4-6 weeks after harvest	MacQueen,1965 Nuttal *et al.*, 1961

Annex 2 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Remarks	Reference
Canada (cont.)						
Autum spice	0.02-0.12	10°	2,4,6,8 and 10 weeks	300 days	Maximum effect on sprout inhibition when irradiated 2 weeks after harvest	MacQueen,1965 Nuttal *et al.*, 1961
Czechoslovakia						
Vsetatska	0.04-0.06	11-18.5°	6 weeks	7 months	Complete sprout inhibition	Salkova *et al.*,1978
Denmark						
Hollandsk, Perijka, Rijnsburger, Zittauer	0.06-2.50	RT;5°, 50-60%	2 weeks, 1 and 2½ months		Good sprout inhibition when irradiated with 0.06 kGy within 2 wks after harvest	Skou, 1971
Egypt						
Seidi (Giza 6)	0.02-0.08	RT		1 year	Satisfactory sprout control with 0.06-0.08 kGy	Zidan, 1967
Giza 6	0.08	RT		7 months	Reduced sprouting	Salems, 1974
Giza 6, Seidi(Giza 6)	0.03-0.09	RT(11-29°);		1 year		Roushdy *et al.*,1966, 1973

Annex 2 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Remarks	Reference
France						
Unspecified	0.12					Vidal, 1966
Germany, Fed. Rep. of						
Granada, Ontario Rocket, Topas	0.05 and 0.10	10°, 80%; 20°; 60%	3,5 and 9 weeks		Complete sprout inhibition when irradiated within 3 weeks after harvest; Irradiation at 5 weeks after harvest inhibited sprouting at 20°C	Diehl, 1977
Hybride, Zittaner	0.08 and 0.08 (Bremsstrahlung)	2-15°, 70-75%		8 months	Complete sprout inhibition not observed	Penner *et al.*, 1972
Granada, Hyduro Juwarund, Ontario, Rocket, Topas	0.05 and 0.10 (10MeV electrons)	4°; 80%; 9°; 75%; 10°; 80%; 20°; 60%	1-2, 4-5, 8, 11 and 21 weeks	Up to 12 months	Complete sprout inhibition at 0.05 kGy when irradiated not later than 4 weeks after harvest	Grunewald, 1978
Hungary						
Mako, Strigunovsky	0.05-0.15	4-10°; 78-85%	2,6,9 and 20 weeks	10 months	Complete sprout inhibition not observed even in onions irradiated at 0.05 kGy, 2 weeks after harvest.	Farkas, 1975

Annex 2 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Remarks	Reference
Hungary (cont.)						
Mako	0.03-0.07	0-4°;80%	3-6 weeks	10 months	Stronger sprout inhibition when irradiated before the break of dormancy	Mahmoud *et al.* 1978
Alsogodi,Aroma, Dorta,diparma, Mako	0.05	0-16°	2-7 weeks	7 months		Kalman *et al.*, 1978
India						
Red Globe	0.06	21-25°; 57-90%;		8 months	Complete sprout inhibition	Dharkar,1966; Lewis & Mathur 1963
Red Globe	0.03-0.18	10-12°; 85-90%;RT			Complete sprout inhibition above 0.09 kGy	Nandpuri *et al.*, 1969
Red Globe	0.06-0.15	4°;70-80%; 12°;64-72%; 19°;70-75%; 29°;62-76%	2 months	2 months	No sprout inhibition	Thomas *et al.*, 1975
Red Globe	0.06-0.25	18-20°; 70-75%; 29-32°; 40-65%	1 month	1 month	No sprout inhibition	Thomas *et al.*, 1975

Annex 2 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Remarks	Reference
India (cont.)						
Red Globe	0.06-0.25	18-20°; 70-75%; 26-32°; 40-65%	7,14,21, 28,42 and 57 days	6 months	Good sprout control at 0.06 kGy when irradiated 2 weeks after harvest	Thomas *et al.*, 1975
White Globe	0.06	26-32°; 40-65%; RT		4 months		Nair *et al.*, 1973
N-53 Red Globe	0.06			5 months	Complete sprout inhibition under commercial ambient storage conditions	Thomas *et al.*, 1986
Iran, Islamic Rep. of						
Red	0.03-0.09	8°,75-85%	2½-3 months	12 months		Sekhavat *et al.*, 1978
Iraq						
Red,White	0.03-0.12	14-34°(RT)	2 months	10 months	Complete sprout inhibition at 0.06-0.09 kGy	Auda&Khalaf 1979

Annex 2 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Remarks	Reference
Israel						
Beit Alpha	0.02-0.12	0°, 65-70%; RT	1, 15, 20 28, 25 and 40 d	7 months	Good sprout control 0.07-0.12 kGy	Kahan and Temkin-Gorodeiski, 1968
Riverside, Egyptian, Grano	0.07-0.80	0°; 10-30° (RT)		8-9 months		Temkin-Gorodeiski et al., 1972
Riverside, Egyptian, Grano	0.07	RT		6-9 months		Padova *et al.*, 1969
Japan						
Senshu-nakadaka	0.03-0.15		57, 86 and 114 days		Complete sprout inhibition when irradiated at 57 and 86 days after harvest	Ojima *et al.*, 1963
Unspecified	0.01-0.15	0-2°, 13°, RT			Reduced sprouting at 0.03 kGy	Meshitsuka *et al.*, 1962
Senshuki	0.07-0.15	5°; 8°; RT	Up to 60 days	6-8 months	Satisfactory sprout inhibition at 0.07 kGy when irradiated within 60 days after harvest	Takano *et al.*, 1972a

Annex 2 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradia-tion after harvest	Storage period	Remarks	Reference
Japan (cont.)						
Sapporoki	0.03-0.60	5°;10°; RT	27,35,88 and 104 days	8 months	Complete sprout inhibition at 0.03-0.15 if irradiated within 1 month of harvest	Takano *et al.*, 1974d
Furanui, Kitamaki, Ohotsuku	0.038-0.15	0°,5°, 14-26°	Within 3 weeks	6 months	Good sprout inhibition	Kawashima et al.,1982
Sapporki	0.03-0.15	1°,6°,20° RT	2 and 4 weeks		Good sprout suppression when irradiated 2 weeks after harvest	Chachin *et al.*, 1973
Senshuki, Sapporki	0.07 and 0.15	5°,RT	20 and 60 days	8 months	Almost complete sprout inhibition in Senshuki when irradiated from 20-60 days after harvest with 0.07 kGy	Umeda et al., 1970
Unspecified	0.03-0.15	3°	within 1 month	8 months	Complete sprout inhibition	Aoki,1977
Korea, Rep. of						
Paichong, Cheon Ju Hwang	0.04-0.12		1 week; 2 and 3 months		Complete sprout suppression at 0.04-0.08 kGy if irrad-iated within 1 week after harvest	Kim *et al.*, 1970

Annex 2 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Remarks	Reference
Korea, Rep. of (cont.)						
Unspecified	0.04-0.15	5°, RT, (15-30°)	11, 32, 51, 66, 89 and 96 days		Increasing dose levels needed to inhibit sprouting when irradiation time is delayed, no effect when irradiated at 96 days after harvest	Park *et al.*, 1972
Paichong, Cheon ju Hwang	0.10-0.25	2-20°; 70-80%		8 months	Complete sprout inhibition in Cheon Ju Hwang, 2-4% sprouting in Paichong	Cho, 1982
Netherlands	0.02-0.06		immediately after harvest and 2 weeks		Irradiation within 1-2 weeks after harvest strongly suppresses sprouting	de Zueeuw, 1975, Sparenburg, 1975
Nigeria						
D_sXW_s78	0.05-0.15	20-25°, 20-82%	2 weeks	7 months	Complete sprout inhibition	Agbaji *et al.*, 1981
Pakistan						
Punjab red	0.02-0.10	22-24° 20-82%		250 days	Complete sprout suppression at 0.08-0.10 kGy	Mumtaz *et al.*, 1970

Annex 2 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradia- tion after harvest	Storage period	Remarks	Reference
Pakistan (cont.)						
Local	0.10	14-16°, 60-70% 25-40°, 40-50%		8 months		Khan and Wahid, 1978
Philippines						
Red creole	0.04-0.16	1-3°, 70-75;	1-2 weeks			Gonzales et al., 1969
Red creole		2-5°, 70-75; 25-34°, 60-90%		9 months		Singson *et al.*, 1978
Yellow Granex	0.04-0.11	2-5°, 70-75%; 25-34°, 60-90%		9 months		Singson *et al.*, 1978
Yellow Granex	0.10	2-5°, 70-75%; 24-33°, 60-90%		7-10 months		Lustre *et al.*, 1981
Sri Lanka						
Vethala, Small onion	0.02-0.15	RT,65-80%; 10°	3 weeks	4 months		Theivendirarjah, 1982

Annex 2 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Remarks	Reference
Switzerland						
Superba, Seva, Hyper, Hygro, Royal Sluis 1962, Royal Sluis 1905, Wijo	0.08	-1 to 1° 10°		8-10 months		Zehnder, 1984
Thailand						
Unspecified		10-12°	15 days	6 months		Tiravet & Chantharaskul, 1972
Unspecified	0.067-0.094	5-10°, 70-80%		3 months		Loaharanu, 1974
USA						
Southport White Globe	0.11 and 0.93	21°	2 months	54 days	More sprouting after irradiation	Mullins and Burr, 1961
Hybrid strain W-45	0.02-2.5	21.1°;46%	12,76 and 118 days	190 days	Good sprout control at 0.02 kGy when irradiated 12 days after harvest	Dallyn *et al.*, 1955
Sweet Spanish White & yellow strains	0.01-0.12				Complete sprout inhibition at 0.08 and 0.12 kGy	Dallyn & Sawyer 1954, Sawyer & Dallyn, 1959

Annex 2 (cont.)

Country/ Cultivar	Dose used (kGy) (Optimal dose)	Storage temperature (°C; RH)	Time of irradiation after harvest	Storage period	Remarks	Reference
USA (cont.)						
Pearl	0-0.28	10°;50%				Brownell *et al.*, 1957;
Spanish	0.07-0.28					Brownell *et al.*, 1957;
White Portugal Yellow Ebenezer	0-016-0.128				Reduced sprouting	Hopen *et al.*, 1957
USSR						
Gribovskii	0.10-3.00	2°;85-90%				Korableva & Metlitsky, 1963
Unspecified	0.06-0.12					Metlitsky *et al.*, 1963
Venezuela						
Islena Yellow	0.02-0.04	10-22°, 60-95%		8 months	Complete inhibition of sprouting at 0.03 kGy and above	Solanas and Darder, 1963; 1964, 1968
Unspecified	Up to 0.08	19°,78%		16 weeks		Guma and Rivetti, 1970
Yugoslavia	0.07					Blinc, 1959

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No. 1 Guidelines for Preparing Regulations for the Control of Food Irradiation Facilities

No. 2 Draft International Inventory of Authorized Food Irradiation Facilities

No. 3 Code of Good Irradiation Practice for Insect Disinfestation of Cereal Grains (available also in Spanish)

No. 4 Code of Good Irradiation Practice for Prepackaged Meat and Poultry (to control pathogens and/or extend shelf-life) (available also in Spanish)

No. 5 Code of Good Irradiation Practice for the Control of Pathogens and other Microflora in Spices, Herbs and other Vegetable Seasonings (available also in Spanish)

No. 6 Code of Good Irradiation Practice for Shelf-life Extension of Bananas, Mangoes and Papayas (available also in Spanish)

No. 7 Code of Good Irradiation Practice for Insect Disinfestation of Fresh Fruits (as a quarantine treatment) (available also in Spanish)

No. 8 Code of Good Irradiation Practice for Sprout Inhibition of Bulb and Tuber Crops (available also in Spanish)

No. 9 Code of Good Irradiation Practice for Insect Disinfestation of Dried Fish and Salted and Dried Fish (available also in Spanish)

No. 10 Code of Good Irradiation Practice for the Control of Microflora in Fish, Frog Legs and Shrimps (available also in Spanish)

No. 11 Irradiation of Poultry Meat and its Products – A Compilation of Technical Data for its Authorization and Control *(IAEA-TECDOC-688)*

No. 12 Irradiation of Spices, Herbs and Other Vegetable Seasonings – A Compilation of Technical Data for its Authorization and Control *(IAEA-TECDOC-639)*

No. 13 Irradiation as a Quarantine Treatment of Fresh Fruits and Vegetables – Report of a Task Force Meeting held in Bethesda, Maryland, USA, January 1991

No. 14 Training Manual on Operation of Food Irradiation Facilities, First Edition

No. 15 Guidelines for the Authorization of Food Irradiation Generally or by Classes of Food

No. 16 Training Manual on Food Irradiation for Food Control Officials

No. 17 Irradiation as a Quarantine Treatment of Fresh Fruits and Vegetables - Report of a Working Group Meeting held in Washington, D.C., March 1994

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No. 20 Code of Good Irradiation Practice for Insect Disinfestation of Dried Fruits and Tree Nuts

No. 21 Control of Irradiated Food in Trade – A compilation of principles and international recommendations for regulatory control measures

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Other publications issued under the auspices of ICGFI

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Facts about Food Irradiation (a set of 14 "Fact Sheets" covering all aspects of food irradiation issued as public information) *(IAEA, 1991)* (available in Arabic, English, French, Russian, Spanish, Portuguese, and Japanese)

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Irradiation of "Red Meat" – A compilation of technical data for its authorization and control *(IAEA-TECDOC-902)*