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Shelf-stable foods through irradiation processing

Report prepared by the Food Preservation Section, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture

FOREWORD

Irradiation in combination with other food processes/treatments, at sterilizing or at substerilizing doses, has long been known to be capable of yielding shelf-stable foods, particularly dry-packed meat, poultry and fish/shellfish products having very good eating quality and nutritional value. However, other than highly specific, targeted uses with astronauts and cosmonauts in space, with immune-suppressed medical patients at one US hospital, and for military feeding plus supplying small niche 'markets' in the Republic of South Africa, there has been no commercial exploitation of the research and development that has gone into establishing this potentially very useful and valuable food irradiation application category. But what with rising global energy costs, and immune-compromised/suppressed populations on the increase, together with increasing consumer demand for minimally processed superior eating quality foods in developed countries especially, the potential and need for industrial use of this largely neglected food irradiation area is becoming more and more apparent.

A Consultants Meeting on Irradiation for Shelf-Stable Foods was held in Vienna from 11 to 15 October 1993. This report is based on the discussions and conclusions of that meeting.

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INTRODUCTION

A Consultants Meeting on Irradiation for Shelf-Stable Foods was convened to evaluate the role of irradiation in increasing the availability, improving the quality and reducing the cost of shelf-stable foods; also, to consider the need for a research and development programme to be carried out by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture.

The consultants were informed that the International Consultative Group on Food Irradiation (ICGFI), established under the aegis of FAO, IAEA and WHO in 1984, has been compiling data on wholesomeness of food irradiated with doses above 10 kGy. Once the compilation is completed, FAO, IAEA and WHO will be asked to evaluate these data and to determine whether additional studies, if any, would be required to consider food treated with doses above 10 kGy to be wholesome.

Within the scope of the meeting, it was agreed to define "shelf-stable" foods as those which have been prepared to have the capacity for long, safe storage under declared ambient conditions, without undue loss of nutritive value and of sensory acceptability. Such products may also include those which are sterile and suitable for medical purposes. For the purpose of this report irradiation will be a significant component of the process.

1. COMBINATION PROCESSING OF FOOD INVOLVING IRRADIATION AT DOSES BELOW 10 kGy

There is an increasing consumer demand for food which is safe, fresh or fresh-like, visually attractive, full-flavoured, nutritious, convenient to prepare and serve, with decreased use of preservatives, available throughout the year, and at reasonable cost. As a result, minimally processed, chilled foods have been marketed increasingly in several advanced countries to satisfy consumer demand. Such foods, however, could introduce new microbiological risks, in view of emerging problems related to certain pathogenic microorganisms which can grow under chilled conditions, e.g., *L. monocytogenes, Yersinia*, etc. Combination treatments involving irradiation could ensure the hygienic quality of products while retaining the quality demanded by the consumers.

Developing countries require wholesome food with a prolonged shelf-life, often without the use of refrigeration. Irradiation in combination with other processes could result in products which can be distributed easily under tropical conditions. Combination treatments could also be used for improving the microbiological safety and quality of cooked, chilled food and prepared meals stored either under refrigeration or at ambient temperature.

In order to generate data required for the foregoing, a Co-ordinated Research Programme on Irradiation in Combination with other Processes for Improving Food Quality was initiated by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture in 1991. The effects of irradiation at doses below 10 kGy in combination with other treatments, e.g. heat, low water activity, pH, modified atmosphere, salting, acidulants, packaging, etc. to bring about microbiological safety, improved sensory properties, increased shelf-life and convenience in distribution and use, are being investigated. The results achieved so far may be summarized as follows:

1.1. SHELF-LIFE EXTENSION OF MEAT AND FISH

Irradiation investigated up to a dose of 3 kGy in combination with environmental stress factors, e.g. reduced pH and a_w, and/or sensorily acceptable acidulants or humectants, could substantially increase the shelf-life of fresh meat and poultry and their products stored under chilled conditions. Normally, such products are stored and marketed under frozen conditions in several countries. In addition, shelf-life of semi-dried fish can be enhanced by using irradiation in combination with salting, drying and appropriate packaging.

1.2. MICROBIOLOGICAL SAFETY OF FOOD

Low dose irradiation of ready-to-eat meals was found to be effective for controlling non-spore forming bacterial pathogens. Irradiating at doses as low as 1.5 kGy could be used for inactivating pathogenic microorganisms, e.g. *V. vulnificus* and *V. parahaemolyticus* which are intrinsic to raw seafood such as oysters and clams which are often consumed raw.

1.3. USE OF COMBINATION PROCESSES ON COMPOSITE FOOD AND PREPARED MEALS

Irradiation up to a dose of 3 kGy improves microbiological quality of prepared meals composed of roast beef, gravy and certain vegetables and those composed of salmon, vegetables and dairy components, stored under refrigeration. A combination of an irradiation treatment (up to 45 kGy) and heat treatment (F_0 value of 1 to 2) results in shelf-stable composite food and meals of superior quality to products sterilized by either heat or irradiation alone. The suitability of various packaging materials for irradiated composite food and prepared meals are also being investigated.

The above mentioned applications, which are being addressed through a co-ordinated research programme sponsored by the Joint FAO/IAEA Division, were considered to be outside the scope of this meeting.

2. SHELF-STABLE FOODS THROUGH IRRADIATION PROCESSING

Traditionally, shelf-stable foods have been produced by the food industries by the application of extreme techniques which are incompatible with high quality products. Examples include: heat sterilization, acidification to low pH values, severe drying, use of high salt levels in curing and use of added preservatives.

In order to minimize damage to product quality, a strong trend in processing techniques in recent years has been to move increasingly towards the application of less extreme processing, e.g. by the use of combination preservation techniques. This trend towards minimal processing can introduce increased risk due to reduction in the efficacy of inactivation or inhibition of microbial pathogens.

It is imperative that the assurance of safety that the consumer has come to expect and assume is maintained. Irradiation can be an integral part of the development of new systems that target minimal processing and contribute to the maintenance of the expected and assumed degree of safety assurance.

With respect to non-sterile products, attention must be given to a wide range of vegetative and spore-forming pathogens. With respect to sterilized products, the key organisms of concern are the various types of *Clostridium botulinum*.

The meeting paid particular attention to the use of irradiation at doses above 10 kGy, in combination with other processes, which would result in shelf-stable products (i.e., which can be stored without the use of environmental control for a significant period of time). With the phasing out of chlorofluorocarbons (CFCs) which are widely used by the refrigeration industry for food distribution, there is a need to evaluate the potential for the development of products which can be distributed and marketed without refrigeration. In many developing countries, the phasing out of CFCs would result in less availability of food of animal origin as well as higher cost of such food to the local population. Therefore, there is an increasing interest in such prepared shelf-stable meals which are currently marketed under frozen or chilled conditions. An investigation should be made of the market potential for such products at ambient temperature using combination treatments involving irradiation.

A variety of shelf-stable food products would also attract the interest of several target groups e.g., yachtsmen, campers, hikers, mountain climbers, and those who receive food through emergency relief operations. Irradiation could result in high quality shelf-stable food especially those of animal origin, for these population groups. Such foods have been successfully used by astronauts and armed forces personnel in some countries.

Another type of shelf-stable food products are radiation-sterilized meals intended mainly for medical use (eg. by hospitals for organ transplant patients) and other vulnerable groups of individuals under medical care. While a few countries (Finland, the Netherlands, U.K and South Africa) specifically permit radiation-sterilized food for such uses, the availability of such food is very limited.

3. MICROBIOLOGICAL SAFETY OF IRRADIATED SHELF-STABLE FOODS

3.1. STERILE FOODS

In the context used here shelf-stable food is food that has been processed in such a manner that it has an extended shelf-life without environmental control (see definition in the Introduction). Because such products are stored under conditions that will support the growth of pathogenic microorganisms, means must be provided either to prevent the growth of such organisms or to eliminate them from the food product entirely. Of conventional technologies only retort processing will eliminate all pathogenic microorganisms from the food and only at the expense of changing the nature of the food. Treatment of the food with ionizing radiation can eliminate even the most resistant of foodborne pathogens, *Clostridium botulinum*, from food without deleterious effects on the quality of the food. *C. botulinum* is the primary concern because of its resistance to radiation and heat, and its potential for toxin production, and because most of these products will be canned or packaged in air-impermeable pouches, and therefore by definition may be stored at ambient temperatures. Irradiation processing intended to eliminate *C. botulinum* will also eliminate all other bacterial pathogens such as *Clostridium perfringens, Bacillus cereus, Staphylococcus aureus, Salmonella spp., Campylobacter spp., Listeria monocytogenes, Aeromonas hydrophila,* and *Escherichia coli* 0157:H7 (Table I). In addition parasitic organisms will also be eliminated.

Organism	Substrate	Irradiation temperature	12D-Value kGy	Reference
A. hydrophila	Beef	5°C	1.7	16
C. botulinum	Beef	-30±10°C	37.0	8
C. botulinum	Beef	-30±10°C	41.2	5
C. jejuni	Beef	-5°C	5.28	15
E. coli O157:H7	Beef	0-5°C	1.93	19
C. botulinum	Pork	ambient	43.3	1
C. botulinum	Pork	-30±2°C	43.7	7
C. botulinum	Chicken	-30±2°C	42.7	7
C. jejuni	Turkey	0-5°C	2.23	15
L. monocytogenes	Chicken	2-4°C	9.24	14
S. aureus	Chicken	0°	4.32	18
S. enteritidis	Chicken	2°C	7.10	20
S. typhimurium	Chicken	2°C	4.72	20
C. botulinum	Bacon	1.7-10°C	26.5-28.7	4
C. botulinum	Ham	2-5°C	29.0	2
C. botulinum	Corned beef	-30°C	25.7	3
C. botulinum	Pork sausage	-30°C	23.9	3

3.2. NON-STERILE, SHELF-STABLE FOOD

Shelf stability may be attained by a number of methods. Such food may be contaminated with foodborne microbial pathogens that could be eliminated by treatment with ionizing radiation. In such food the growth and potential toxin formation by spore forming bacteria will be inhibited by standard food technological methods such as by reduced water activity. *Salmonella, Staphylococcus, Listeria, Aeromonas, E. coli* O157:H7, and *Campylobacter* can all be eliminated by treatment with ionizing radiation doses generally not exceeding 3.0 kGy. Such infectious parasites as *Toxoplasma gondii, Trichinella spiralis, Cysticercus bovis*, and *Cysticercus cellulosae* will also be inactivated by very low doses of radiation.

4. SUCCESSFUL RADIATION-STERILIZED SHELF-STABLE PRODUCTS

Meat and seafood products of exceptional high quality have been produced and used in the USA and South Africa. These products include:

1. Food used during manned space flights

	Dose range (kGy)
Beefsteak	37–43
Corned beef	25–29
Turkey slices	37–43
Ham	37–43
Pork sausage	27–33

(Ref. E.S. Josephson, 1983. Radappertization of meat, poultry, finfish, shellfish and special diets. In "Preservation of Food by Ionizing Radiation" Vol III, E.S. Josephonson and M.S. Peterson (Eds). CRC Press, Boca Raton, Florida).

2. Radappertized Foods Developed by US Army Natick Laboratories, Natick, MA, USA

	Dose range (kGy)
Roast beef	37–43
Beef steak	37–43
Ham	37–43
Corned beef	25–29
Turkey slices	37–43
Pork sausages	27–33
Chicken	45–54
Cooked salami	25–27
Shrimp	38–49
Codfish cake	32 (min.)
Bacon	25.2 (min.)
Pork shop	43.7 (min.)

(Ref. E.S. Josephson, 1983. Radappertization of meat, poultry, finfish, shellfish and special diets. In "Preservation of Food by Ionizing Radiation" Vol III, E.S. Josephson and M.S. Peterson (Eds). CRC Press, Boca Raton, Florida).

3. Shelf-stable irradiated food developed in South Africa

Meat Dishes	**Starches**	**Vegetables**
Meat loaf	Stir–fry rice	Peas
Smoked Viennas	Maize meal porridge	Tomato & onion mix
Roast chicken	Sweet potatoes	Baby carrots
Country sausage	Kidney beans	Baby carrots & peas
Beef curry	Yellow rice	Cabbage
Chicken and tomato	White rice	Mixed vegetables
Chicken casserole	Savoury white rice	Sweetcorn
Bobotie	Stir-fry wheat	
Beef steak in gravy	Savoury yellow rice	
Chicken stew		
Smoked chicken		
Boerewors		
Steak		
Meat balls		
Chicken curry		
Beef stew		
Roast beef		
Hamburgers		

The use of these foods has been limited by lack of national regulations. For example, no general clearance on radiation sterilized food has been given by the US FDA. In South Africa, the use by the military does not require special regulations but use by specific groups of other personnel (yatchsmen/expeditions) on the basis of need requires permission from national authorities.

5. BENEFITS OF SHELF-STABLE FOOD TO THE FOOD INDUSTRY AND CONSUMERS

The majority of food preservation procedures currently in use act by *inhibiting* the growth of microorganisms to varying extent (Table II). These procedures include, for example: the use of low temperature in chill, 'superchill' and frozen storage; reduction in pH value by addition of specific organic acids; reduction in water activity by the addition of salts, sugars or other solutes, or by drying oxygen-free, vacuum or nitrogen packaging; carbon dioxide-enriched modified atmosphere packaging; and addition of organic or inorganic preservatives.

In contrast, few procedures are used that act by *inactivating* the microorganisms of food-poisoning or food spoilage concern. Heat remains by far the most commonly-used inactivation technique.

With regard to effective control of food-borne pathogens, it can be argued that improved and new inactivation techniques, targeting microorganisms of concern rather than minimization or 'inhibition' of their growth, is urgently required if consumer safety is to be maintained or improved.

TABLE II. CURRENT AND POTENTIAL FOOD PRESERVATION TECHNOLOGIES

Objective	**Factor**	**Mode of achievement/example**
Slowing down or inhibition of microbial growth	Lowered temperature	Chill-storage 'Superchill' storage
	Reduced water activity/raised osmolality	Drying and freeze-drying Curing and salting Conserving with added sugars
	Microstructure control	Compartmentalisation of aqueous phases in water-in-oil emulsions
	Decreased oxygen	Vacuum and nitrogen packaging
	Increased carbon dioxide	Carbon dioxide-enriched 'controlled atmosphere' storage or 'modified atmosphere' packaging
	Acidification	Addition of acids/fermentation
	Use of cultures	Addition of microorganisms and culture products
	Alcoholic fermentation	Brewing, vinification Fortification
	Use of enzymes	Addition of: - lysozyme - lactoperoxidase
	Use of preservatives	Addition of preservatives: - inorganic (e.g. sulphite, nitrite) - organic (e.g. propionate, sorbate, benzoate, parabens) - antibiotics (e.g. nisin, pimaricin)

Inactivation of microorganisms	Heat	Pasteurization Sterilization
	Ionising irradiation	Radurization Radicidation Radappertization
	Chemicals	Treatment of ingredients (e.g. with ethylene oxide) Treatment of packaging materials (e.g. with hydrogen peroxide, and/or heat, irradiation)
	Enzymes	Addition of lysozyme
	Pressure	Application of high hydrostatic pressure
	Electric shock	Application of high voltage pulses
Restriction of access of microorganisms to foods	Packaging Aseptic processing	Aseptic processing and packaging without recontamination

Gould, G.W. (1989). Mechanisms of Action of Food Preservation Procedures. Elsevier Science Publishers, London.

5.1. INACTIVATION VERSUS INHIBITION

The number of reported cases of food-borne illness continues to rise in developed and underdeveloped countries although the means for control of the growth of pathogens in foods are now relatively well-known. Whilst major outbreaks are often traced back to source, the majority of cases are sporadic and seldom traced to source.

Most sporadic cases are thought to occur as a result of lapses of hygiene, e.g., in the home or in the catering establishment. However, the underlying reason why such lapses cause problems is the occurrence of the organisms in those environments in the first place; e.g., entering the home on contaminated foods. Lapses of hygiene will *always* occur. Substantial progress in the reduction in food-borne disease will therefore only be achieved if techniques are introduced to prevent the organisms of concern from entering the home or catering environments.

That being so, a major target for research must be the development of more effective *inactivation* techniques. Techniques for growth *inhibition* should be given priority only in those instances where *inactivation* is judged to be impractical.

Irradiation offers a key process that should be integrated with the other available techniques to inactivate targeted organisms from those foods which present greatest risks.

5.2. PREDICTIVE MODELLING OF MICROBIAL SURVIVAL, INACTIVATION AND GROWTH

Means for the *inhibition* of microbial growth in foods are reasonably well-developed and facilitated by the increasing availability of predictive microbiology models. These are generally constructed from experimentally-derived data on the effects of factors such as temperature, pH, a_w, concentrations of salts and acids, gases, etc., on the growth and survival of microorganisms. The models can then be interrogated to generate predictions of the effects of changes and of combinations of factors. These predictions are of potentially great value to the food industries. They allow confident derivation of safe, stable, new or modified foods, processes and distribution systems, without the need for time-consuming and costly inoculated pack studies or challenge testing. Predictive models accessible to the food industries are being developed in the USA, the UK, Australia, and in Europe in an Economic Union-funded project including over 30 laboratories in 11 countries.

Irradiation has yet to be included in these predictive models as a factor affecting microbial growth and survival. Application of irradiation by the food industries would be greatly encouraged if irradiation *were* included in such models. A research initiative to build up an irradiation models base could, therefore, be attractive and rewarding.

5.3. 'NUDGING' FOOD PRODUCTS TO SHELF-STABILITY

Many long chill-stable or limited ambient-stable foods that are marketed currently around the world are *close* to complete shelf-stability. In some instances small changes, e.g, to formulation, processing or packaging have been sufficient to 'nudge' such products to complete shelf-stability. In many such products, irradiation may be a preferred route to supply the 'nudge'.

Examples where ambient-stability has been so-achieved include: the so-called 'SSP' (shelf-stable products) meat products, in which proper control of water activity (<0.95) with nitrite and "in-pack" pasteurization ensures stability; fermented dry sausages in which formulation just below a_w 0.82 ensures that oxygen-free packaging stops the growth of spoilage yeasts that would otherwise grow at a_w values down to near a_w 0.6; intermediate moisture fruit pieces in which vacuum-packing or mild heat pasteurization likewise controls growth of yeasts and moulds.

In many such instances, irradiation could be an industrially attractive adjunct that would provide the 'nudge' to achieve ambient stability and this would be most attractive in those instances in which a definite organoleptic advantage resulted. For example in allowing minimal heating and consequent minimal damage to product quality (eg. of a meat snack product); in allowing intermediate moisture fruit pieces to be formulated at higher a_w and hence moisture levels than previously, with advantages regarding yield and texture.

A possible target for research that would encourage the development of new or improved ambient-stable foods world-wide could, therefore, be to concentrate effort on such foods, typical of different countries, that are nearly shelf-stable. Techniques such as pasteurization, modified atmosphere packaging, etc., may be sufficient in some cases to 'nudge' such products to shelf stability. In others, irradiation may offer advantages with respect to sensory quality, presentation and safety.

5.4. OVERCOMING FOOD INDUSTRY RELUCTANCE

The reluctance of food industries to include irradiation in their portfolios of procedures for preservation and safety could be overcome by a number of actions in addition to those that attempt to overcome the reluctance of consumers and retailers to accept irradiated foods. These actions include:

- A new concentration on *inactivation* as the only viable route to achieve a real reduction in food poisoning in the general population, and to deliver highly decontaminated foods for special purposes, e.g., patients on immunosuppressive therapy.

- The integration of irradiation as a factor into the new predictive microbiology models databases that are becoming available worldwide for food industry use, and so far do not include irradiation.

- The specific targeting of long-chill and limited-ambient stable foods worldwide for which irradiation could provide a sensorially-advantageous 'nudge' to extended ambient-stability.

6. SHELF-STABLE IRRADIATED "MEDICAL FOODS" FOR AT-RISK PATIENTS — THE US EXPERIENCE

From the early 1950s to around 1980 the United States Army food irradiation programme developed methods and technology for the production of shelf-stable, radiation-sterilized meal components of high eating quality, nutritional value, safety and stability, even under extreme ambient temperature/humidity storage conditions. These are principally 'dry-packaged' (i.e. without a gravy, sauce or brine since unlike canning, no heat convection is required) meat, poultry and seafood items, hermetically vacuum sealed in multi-layer aluminum foil pouches that provide a total barrier against air, moisture and microbe transmission. These products were developed by the Army for use as field rations; however, they can equally serve as foods for medical patients who require sterile diets, and other 'niche markets' that need or prefer long-term shelf stable foods offering high quality and safety, at an acceptable price, in an occupational or recreational use context. The process is described in Appendix C.

6.1. RADIATION-STERILIZED PRODUCT USE

Such products can be eaten directly out of the pouch, or they can be first warmed in a microwave oven after removal from the pouch, or, by a conventional heating unit either in or out of the pouch. Although they were developed by the US Army as field rations, they have yet to be used as such, except in large scale military feeding trials, because it is US Army policy to purchase and serve only foods that are FDA-approved and/or that are or could be in regular commercial production for the mass civilian consumer market in the USA. For radiation-sterilized foods to be widely available, the US Food and Drug Administration would have to be petitioned formally for their approval, which is a complex and lengthy process.

However, in the special case of radiation-sterilized shelf-stable foods as diet components for at-risk medical patients ("medical foods", e.g., for immuno-compromised/suppressed bone marrow and organ transplant or AIDS patients) a recommendation by a Joint

FAO/IAEA/WHO Expert Committee on Food Irradiation (JECFI) as to their wholesomeness, and/or the US-FDA standard petitioning-and-approval process, for example, should not be necessary. In fact, a few countries (Finland, Netherlands, UK) have already approved radiation-sterilized meals for medical use, although these approvals have yet to be implemented. Also, as noted elsewhere in this consultants meeting report the Republic of South Africa has adopted the methodology worked out under the US Army programme and has done considerable radiation-sterilized shelf-stable product development/formulation, also in the context of military feeding, and can make a wide variety of such products available on order.

Regulatory actions may occur in the USA to approve such products for medical use for the following reasons: (1) like many, if not all countries, the US is seeing an increase in the number of medical patients and others with weak or non-functioning immune systems who should be or must be on sterile diets, (2) the American Medical Association (AMA), whose physician members would be the ones to prescribe radiation-sterilized foods to their patients, supports food irradiation for its ability to eliminate pathogenic microorganisms and thereby help protect public health, (3) the US-FDA has a mechanism for approval of special "medical foods" (e.g., foods formulated to have specific nutrient compositions for special needs) and, (4) there have already been two limited, but very successful experiences with radiation-sterilized meal components in the USA. For nearly twenty years the US National Aeronautics and Space Administration (NASA) has been using several radiation-sterilized meat and poultry items on manned space flights, and these have been very popular with the astronauts. Also, at one US hospital, the Fred Hutchinson Cancer Research Center, Seattle, a variety of radiation-sterilized food items were consumed by bone marrow transplant and other immuno-suppressed patients with much success over the period from 1974 to 1988.

The radiation-sterilized meal components used by NASA and by the Fred Hutchinson Hospital came under a special FDA investigational food/drug approval for not-yet-approved items (since irradiation is treated regulation-wise as a food additive in the USA, each irradiated food must receive formal FDA clearance for general use). In 1988 the Fred Hutchinson Hospital discontinued their use, as a small research irradiator used for their sterilization at the nearby University of Washington, Seattle, became too weak to deliver the required high dose in a reasonable period of time, and the next closest irradiator was too far away for practical use. Because products thermally processed to the same high degree of sterility are of too-low-an eating and nutritional quality, the Fred Hutchinson Hospital reverted to "low bacteria-pathogen free" diets that must be indiv-idually tested to assure freedom from pathogens before serving. Such foods could also be produced by substerilizing irradiation to markedly reduce overall microbial counts while assuring freedom from common non-sporeforming pathogens such as the *Salmonellae*. Irradiation of raw poultry to well below the sterilization level to render it virtually pathogen free, has already been approved in the USA and in several other countries, with limited production and distribution in the USA. In principle, such pathogen-safe (subject to testing) product could be used by hospitals or high risk individuals.

Whenever shelf-stable radiation-sterilized food has been approved as "medical food", it could create a niche market and incentive for the industry to develop shelf-stable radiation-sterilized food for hospitals and "high-risk individuals". Such shelf-stable, sterile products could also find other, non-medical ‘niche markets’ that would require full regulatory approval, as through the USFDA petitioning process.

7. CONCLUSIONS

The production of shelf-stable food using irradiation in combination with other processes would result in increased variety, improved quality and would facilitate wide food distribution in both advanced and developing countries. While consumers in advanced countries would be more interested in the variety, convenience and quality of such food, those in developing countries would benefit from such products which can be marketed without the use of refrigeration. The meeting, therefore, agreed that:

1. Technology for producing shelf-stable irradiated food is well established and a number of such products exist, some of which are sterile.

2. Some food products exist that could be made shelf-stable using irradiation at doses below 10 kGy.

3. Under special permissions or regulations, opportunities exist to supply shelf-stable irradiated sterile food to hospitals and individuals on a physician's order.

4. Food irradiation processing techniques are not included in predictive microbiological safety model databases, thereby reducing their accessibility to potential users. This needs to be corrected.

5. The concept of elimination of undesirable microorganisms should be linked to the present status of *risk assessment* in food retailing.

6. The concept of shelf-stable meals should be abandoned in favour of shelf-stable meal components, thereby:

   (a) allowing a permutation of meal components to achieve dietary flexibility.
   (b) avoiding problems associated with diverse processing requirements and overall resulting variability of the shelf-life of components.

Appendix A

MICROBIOLOGICAL SAFETY OF IRRADIATED SHELF-STABLE FOODS

1. STERILE FOODS

In the context used here shelf-stable food is food that has been processed in such a manner that it has an extended shelf life without environmental control. The primary concern about shelf-stable foods is that pathogenic bacterial spore-forming genera, the *Bacilli* and *Clostridia* must be killed or prevented from increasing in numbers and producing toxin during storage. *Clostridium botulinum* is usually used as the test organism because of its resistance to radiation and potential for producing toxin, and because most of these products will be canned or packaged in air-impermeable pouches and by definition may be stored at ambient temperatures. Meat products will be enzyme-inactivated by heat, which will eliminate many spoilage and pathogenic bacteria. The substrate may also affect the survival of a pathogen. The results of studies of the sensitivity of *C. botulinum* in several different types of products are described below:

Beef: El-Bisi (1966) investigated the survival of *C. botulinum* spores in cooked vacuum canned cooked cubed beef round at temperatures from -196 to +20°C. He found that gamma irradiation temperature had little effect on the rate of spore inactivation below -80°C and a small effect above -80°C. Grecz *et al.* (1971) determined the effect of gamma irradiation temperature on the survival of inoculated *C. botulinum* spores in vacuum canned autoclaved ground beef. Spore resistance progressively decreased with increasing irradiation temperature between -196 to 95°C. Anellis *et al.* (1975) conducted an inoculated, irradiated beef pack (1,240 cans) study. Each can contained a mixture of 10^7 spores from 5 type A and 5 type B *C. botulinum* strains. The cans were irradiated at -30 ± 10°C using ^{60}Co as the gamma source. After irradiation the cans were stored at 30 ± 2°C for 6 months and examined for swelling, toxicity, and recoverable botulinal cells. The minimal experimental sterilizing dose based on nonswollen, nontoxic product was 22 to 26 kGy. The 12D dose was estimated to be 37 kGy.

Anellis *et al.* (1979) evaluated the dose necessary to reduce the number of viable spores of a single most resistant strain of *C. botulinum* by 12 log cycles in vacuum canned, enzyme-inactivated beef. The meat (40±5 g/can) was inoculated with 10^7 spores per can of a spore mixture of *C. botulinum* 33A, 36A, 62A 77A, 12885A, 9B, 40B, 41B, 53B, and 67B. The samples were gamma irradiated (0, 14, 18, 22, 26, 30, 34, 38, 42, 46, and 50 kGy) at -30±10°C. The inoculated pack study (1100 cans) had only one partial spoilage point at 22 kGy, and the binomial confidence limit method was used to estimate a 12D dose of 41.2 kGy.

Pork: Anellis *et al.* (1969) conducted an inoculated pack study with 5690 cans of enzyme-inactivated pork loin inoculated with 10^6 *C. botulinum* spores per can. Each lot was seeded with a different strain; five type A and five type B strains were used. The cans were gamma irradiated at 5 to 25°C in 5 kGy intervals from 0 to 50 kGy, incubated for six months at 30°C, and examined for swelling, toxicity, and recoverable *C. botulinum.* The 12D dose was estimated to be 43.3 ± 1.7 kGy. Anellis *et al.* (1976) conducted inoculated pack studies with irradiated pork (2300 cans) to establish the gamma-irradiation (-30 ± 2°C) 12D dose using inocula of 10^7 spores per can of a mixture of 5 type A and 5 type B *C. botulinum* strains. After irradiation the cans were incubated for 6 months and tested for swelling, toxicity, and recoverable botulinal cells. The minimal experimental sterilizing dose based on flat, nontoxic product was 30–32 kGy for pork. The 12D value was estimated to be 43.7 kGy for pork. Note the similarity of the 12D values at -30 and at +5-to-25°C.

Chicken: Anellis *et al.* (1977b) conducted inoculated pack studies with irradiated chicken (2000 cans) to establish the gamma-irradiation (-30 ± 2°C) 12D dose using inocula of 10^7 spores per can of a mixture of 5 type A and 5 type B *C. botulinum* strains. After irradiation the cans were incubated for 6 months and tested for swelling, toxicity, and recoverable botulinal cells. The minimal experimental sterilizing dose based on flat, nontoxic product was 40–42 kGy for chicken. The 12D dose was estimated at 42.7 kGy.

Bacon: was one of the first meat products to be studied extensively for possible commercial ionizing radiation treatment. It was selected because of its relatively short refrigerated shelf life; it cannot be thermally processed without undesired changes in sensory properties; it withstands relatively high radiation doses without significant loss in sensory quality attributes; it is a poor substrate for growth of *C. botulinum*; and it was targeted for reduction of nitrite use and content.

Anellis *et al.* (1965) reported that the 12D gamma-radiation dose for sterilization of sliced, cured bacon, packed *in vacuo* in cans and challenged with approximately 10^6 spores of *C. botulinum* types A and B per can, was 26.5-28.7 kGy . The minimal sterilizing dose was 20 kGy. The authors observed that viable *C. botulinum* spores could survive at least 8 months in storage at 30°C without producing detectable spoilage or toxin production at doses below 20 kGy.

Ham: is frequently temperature-abused and has been the subject of several food irradiation studies. Pratt and Ecklund (1956) reported that irradiated (24 kGy) cured ham had the best flavour of any meat tested. However, Erdman and Watts (1957) irradiated ham in air and observed severe colour losses, off-odours, and marked changes in nitrite levels. Reductions in nitrite were eventually found to be advantageous, and products with good sensory properties were produced (Wierbicki and Heiligman, 1973; Wierbicki *et al.*, 1976).

The microbiology of irradiated hams was investigated in a series of studies (Anellis *et al.*, 1967; Drake *et al.*, 1960; Greenberg *et al.*, 1965). Anellis *et al.* (1967) conducted a large-scale (6350 cans) inoculated-pack study of ham, which was gamma irradiated at 5.0 kGy intervals from 5.0 to 45 kGy. Each can was challenged with approximately 10^6 spores and vacuum sealed. The temperature at the start of the irradiation process was 2 to 5°C and was not permitted to rise above 24°C. A dose of 45 kGy was an adequate sterilization dose. Lots of 1000 cans per dose that received 35 kGy or higher doses were unswollen, nontoxic, and sterile. A few cans (5/2000), which had received doses of 25 or 30 kGy, contained inert but recoverable spores. The highest 12D dose for any strain was 29.0 kGy.

The discovery that the organoleptic properties of ham could be greatly improved by enzyme inactivating the product, packaging *in vacuo*, and irradiating at cryogenic temperature (-30°C), coupled with a reduced nitrite concentration in the cure, required a reassessment of the 12D radiation dose (Anellis *et al.*, 1977a). This inoculated-pack study (1500 cans of ham) established that the 12D value for *C. botulinum*, assuming a log normal rate of kill of 10^6 spores/can of one most resistant strain, was 32 kGy. The inoculum for this study consisted of 5 type A and five type B strains, 10^6 spores/strain.

Corned beef and pork sausage Anellis *et al.* (1972) reported 12D values at -30°C *in vacuo* for corned beef and pork sausage of 25.7 and 23.9 kGy.

The spore formers are the most radiation resistant of the bacterial foodborne pathogens and 12D doses for *C. botulinum* effectively inactivate other bacterial pathogens. For example the 12D value for *Aeromonas hydrophila* in beef is approximately 1.7 kGy (Palumbo *et al.*, 1986). *Campylobacter jejuni* has a 12D value of approximately 1.2 kGy in ground turkey (Lambert and Maxcy, 1984). *Escherichia coli* O157:H7 has a 12D value of approximately 5.28 kGy at -5°C on beef (Thayer and Boyd, 1993). *Listeria monocytogenes* has a 12D value of 9.24 kGy at 2-4°C (Huhtanen *et al.*, 1989). *Salmonella* spp. have 12D values of 4.56 to 9.24 kGy on chicken meat at 0°C (Thayer *et al.*, 1990) and *Staphylococcus aureus* has a 12D value of 4.32 kGy at 0°C on chicken meat (Thayer and Boyd, 1992).

2. NON-STERILE, SHELF-STABLE FOOD

Shelf stability may be obtained by a number of methods most of which do not result in a sterile product. Such foods may become contaminated with foodborne pathogens that could be inactivated by treatment with ionizing radiation. In such foods the growth and potential toxin formation by spore formers will be inhibited by standard food technological methods such as reduced water activity. *Salmonella, Staphylococcus, Listeria, Aeromonas, E. coli* O157:H7, and *Campylobacter* can all be eliminated by treatment with ionizing radiation doses generally not exceeding 3.0 kGy. *Toxoplasma gondii, Trichinella spiralis, Cysticercus bovis,* and *Cysticercus cellulosae* will also be eliminated by very low doses of radiation. The radiation 12D-values for a number of common bacterial pathogens in meat or poultry are summarized in Table I.

Appendix B

SHELF-STABLE MEAL COMPONENTS — THE SOUTH AFRICAN EXPERIENCE

1. INTRODUCTION

During the late 1970s and early 1980s the Atomic Energy Corporation of South Africa (AEC) undertook the development of shelf-stable meat products for use by military personnel under special conditions. The initial request was for raw meat that could be kept at room temperature and cooked when needed. After initial experimentation it was found that although the meat was sterile its structure was degraded by enzyme activity and so it was necessary to examine a process involving pre-cooking. Use was made of data accumulated by the US Army Laboratories at Natick in the 1950s but these data were optimized for local use.

Following success in the area of meat processing the AEC was requested to extend their area of interest to include starches and vegetables.

In 1989 further work was requested to supply meal components for use by Orthodox Jews in military service so that they might be deployed in the field beyond the reach of Kosher food supplies. A special Kosher processing line was developed for this purpose.

To enable the construction of suitable meals from components the evaluation of various accompanying sauces was investigated by AEC through its links with the University of Pretoria (UP) and the Council for Scientific and Industrial Research (CSIR) laboratories in Pretoria.

2. PROCESS METHODOLOGY

2.1. Meat and poultry components

The basic procedure used can be summarized as in Fig.1.

Cook to attain internal temperature of 77°C for at least 10 minutes
(To inactivate enzymes)
↓
Chill in blast chiller (To make handling and vacuum packaging easier)
↓
Slice or portion (if needed)
↓
Vacuum pack
↓
Freeze to -40°C (Mechanical, about 8 h)
↓
Irradiate at 45 kGy (or as recommended by the US Natick) at between -40°C and -20°C
(use dry ice on top of product in totes)
↓
Incubate at 38°C for 10 days
↓
Vacuum pack in 4 layer laminated flexible pouches (Nylon/Foil/Polyester/VLDPE)

Fig.1. Basic procedure for the processing of meat and poultry.

The South African Bureau of Standards, being inexperienced in this type of processing, insisted that the total production output be incubation-verified and not just a percentage, as is common for the canning industry.

Customer requirements placed the main emphasis on the development of whole meat rather than comminuted products such as the turkey rolls or codfish cakes that the US Army Natick Labs. had originated.

Microbiological testing was carried out on all products prior to sensory evaluation to confirm product sterility and safety. In most cases either a trained panel or the process operators, who were experienced but not necessarily trained, carried out the sensory evaluation. Statistical evaluations of results were carried on processed meats, where appropriate, but starches and vegetables were graded only as acceptable or unacceptable and no other statistical data are available.

2.2. Fish

Some processing of fish was attempted using the described method but with little success.

2.3. Starches and vegetables

2.3.1. Vegetables

Initial studies were carried out by cooking certain vegetables, which were then processed further as with the meats. It was found that the products become very soft and mushy after processing. Subsequently, the products were only blanched and then packed, frozen and irradiated.

An extensive experiment was then undertaken to test virtually all available vegetables.

2.3.2. Starches

Initial work with starches showed that they became very soft and mushy after processing and therefore it was decided to only partially cook them for the later studies. Subsequent work was carried out using white rice and two pasta types, i.e. shell noodles and spaghetti. The products were partially cooked, some chilled to 7°C and other frozen at -7°C, -18°C and -40°C. The products were irradiated at 45 kGy at the above temperatures. The irradiation was carried out in the Gammabeam 650 and the temperature could therefore be maintained as required. The products were then stored at room temperature until required for sensory analysis. Control samples were frozen at the different temperatures and kept frozen until required for evaluation.

2.4. Ethnic meals

The basic layout of procedures is as given in Fig. 1. All meats and starches were precooked as discussed earlier. After being cooked and chilled, they were then further processed as in Fig. 1. All vegetables with the exception of the cabbage and tomato and onion mix were bought commercially frozen, weighed into portions, put into the packets in the frozen state, vacuum sealed, frozen to -40°C and irradiated. The cabbage was bought fresh from the market, washed, sliced and boiled for a few minutes until just soft, drained, chilled and then packed and processed as described. The tomato and onion mix was cooked in a tilting frying pan with a number of ingredients, chilled, packed and processed as before.

2.5. Sauces

Initial problems in meal component process development has been restricted by failure of starch based thickeners mainly due to the freezing step in the process. Work by Louw (1991) identified this problem and is now concentrated on development of protein-based thickness especially for meat sauces.

3. RESULTS

3.1. Meat and poultry components

A number of meat dishes were developed successfully and these can be divided into five groups.

(a) Whole meats cooked in convection ovens, chilled, sliced and packed with or without a gravy; e.g., roast beef slices with gravy, roast leg of pork slices with gravy, roast chicken breasts with mayonnaise sauce and bacon.

(b) Steak or hamburger patties, boerewors (beef sausage) fried in a tilting frying pan, chilled and packed with or without a tomato and onion sauce.

(c) Ground meat products, where the meat was precooked in the tilting frying pan, the final product was "assembled" and baked off in the oven, chilled, portioned and packed e.g. bobotie (a local minced meat dish), meat loaf, meat balls and lasagna.

(d) Casserole dishes where the product was stewed in a tilting frying pan, chilled and packed, e.g. beef curry, beef stroganoff, beef stew, chicken curry, chicken and vegetable stew and chicken and tomato casserole.

(e) Commercially processed items that were bought, packed, frozen and irradiated, e.g. country sausage (a Frankfurter type sausage), smoked Viennas and smoked chicken.

General comments on meat dishes

In all cases, meat with low internal muscle fat has been used and excess fat trimmed off the outside of roasts before cooking.

Both the bobotie and lasagna have final toppings consisting of milk based sauces but in the small quantity used these sauces do not pose any sensorial problems. The pasta used in the lasagna tends to become very soft, but again as it was only a small portion of the total dish it has been acceptable.

Sliced beans, diced carrots, diced onions and sliced mushrooms have been used in the chicken and vegetable stew. The onions were sauteed in a little oil after which the mushrooms, precooked chicken and spices were added. This mixture was cooked for approximately 1 hour in a tilting frying pan. Commercially blanched frozen carrots and beans were then added together with the thickeners and the whole mixture was simmered for about 5 minutes. The vegetables tended to become reasonably soft after processing but were still acceptable in the total dish. Seasonal variation in the beans caused certain problems, because if the beans were slightly old they tended to become grey in colour and stringy after processing.

The tomato and onion sauce used in a number of dishes was prepared using chopped onions, tinned peeled tomatoes and a variety of herbs and spices. Because this is already a mushy product it was not affected by the process.

The commercially processed items themselves posed certain problems. It was found that although the smoked chickens were supposed to be hot smoked the commercial smokers did not control their process effectively and, therefore, the chickens were undercooked in the centre. The product was initially perfectly acceptable, but after a period of about 9 months storage began to deteriorate physically due to inadequate inhibition of the enzymes. The meat became very soft and had a slightly soapy feel if rubbed between the fingers. Production of this specific product has ceased as the commercial smokers cannot guarantee a sufficiently "cooked" chicken. The smoked viennas also tended to become soft after a few months and although the product is then perfectly acceptable it has been discontinued.

The specific formulation of the country sausage that was bought was acceptable, but could not be used in Kosher recipes (2.4) This product was initially acceptable but developed a very bitter taste after about 12 months. This again proved that the specific formulation that was used as well as the combination of herbs and spices in irradiated precooked dishes was of the utmost importance. Unfortunately therefore, recipe development has been a time consuming process, because quite often adverse effects were picked up only after about 9 to 12 months of production and storage.

The thickener used in the dishes developed by the CSIR was a thermally stable starch based thickener called "col-flo". This proved to be the most stable of a number of thickeners tested, but was still pretty much unstable. Depending on the different products, sauces become either very thin (the beef stroganoff sauce becomes totally watery) or gel-like (in the case of the beef stew) after the process. In work done by Louw (1991) it was discovered that this is partly due to the pH of the product. Sauces are considered in more detail elsewhere.

Mutton processing was also attempted, but somehow its specific type of fat or other components lead to products with a very rancid taste and smell and after several futile attempts using different recipes and methods of cooking, it was decided to drop this line of research.

Venison and ostrich meat have both been tested, but both are exceptionally dry and tasteless due to the very low fat found in the muscle itself. These meats can be used very effectively in casserole type dishes or in a sauce, but due to the relative cost and availability of the meat, the products were not investigated further.

3.2. Fish

Some work has been carried out on prepared shelf stable fish, but with very little success. This was due mainly to a yellow-brown colour that the products developed after processing as well as a total loss of texture, which resulted in a mushy product. Several different types of fish were studied, e.g. "dry" meat fish like hake, "oily" meat fish like tuna, as well as finely textured and coarsely textured fish. In addition, fish dishes like fish with white sauce, fish pie and fish bobotie were tried, but sensorially, none of these were acceptable.

3.3. Starches and vegetables

3.3.1. Vegetables

The Brassica type vegetables were totally unsuccessful mostly because of a very strong irradiation smell and taste as well as very dark discolouring. Those tested were spinach, broccoli and cauliflower. The spinach and cauliflower also had an almost pink cast to the stalks.

Celery, radishes, leeks, garlic, green peppers, red peppers, bean sprouts, parsnips, turnips, asparagus, vegetable marrows, gem squashes and cucumbers were all not acceptable either due to bad taste, smell or unacceptable colour and texture or a combination of these defects. Aubergines and mushrooms became very limp, turned black and had an unacceptable flavour and odour. However, the mushrooms were acceptable in dishes like beef stroganoff and in the stir-fried rice dishes. Pumpkin became gritty with a dark orange colour and was not acceptable overall. Potatoes became a pink/brown colour and the taste and texture was totally unacceptable.

Sweetcorn was acceptable although slightly gritty directly after processing, but as time progressed, developed a very bitter almost burnt type taste which made the product unacceptable about 9–12 months after processing. Likewise the mixed vegetables, consisting of diced carrots, peas, beans and sweetcorn were also unacceptable after 12 months because of the taste.

The onions became very limp, but were acceptable on taste and smell. Carrots became a dark dull orange colour, slightly limp but still acceptable according to taste and smell. Cabbage and red cabbage became very soft, but were acceptable on smell and taste although the colour became dull. Beetroot and tomato became soft, but still acceptable. Peas became softer, appeared duller, but were acceptable. Runner beans became grey-green and stringy, but if young beans were used, were still acceptable.

In general it was found that the quality of the vegetables was very inconsistent if the initial raw material was bought at the local fresh produce market. The blanching could not be controlled effectively in the kitchen and so commercially blanched frozen products were employed. These vegetables were then used for the 2 years that shelf stable vegetables were supplied on a commercial basis to the SADF. The products supplied were peas, baby carrots, baby carrots with peas, tomato and onion mix, cabbage (this was bought fresh and cooked partially), mixed vegetables and sweetcorn. It was also found that during the process all vegetables lost considerable moisture which had to be poured off before serving.

3.3.2. Starches

The pasta as well as the rice appeared light yellowish in colour. This colour intensified over time. The pasta had an "oily"- shiny appearance. The rice lost a lot of moisture during the process and liquid could physically be poured out of the packet. At the higher temperatures (7°C and -7°C) the product had a distinct irradiation smell and taste, but at the lower temperatures were acceptable with respect to taste and smell. The pasta was very soft and mushy after irradiation and the texture of the rice was gritty. It was decided that none of these were very successful products. After being approached by the customer some of the starch work was repeated. The starches that were considered included rice, maize porridge, kidney beans, sweet potatoes and wheat.

The rice was initially partially cooked and then processed further, but it was found that it became yellowish, gritty, mushy and lost a lot of moisture. In an attempt to counter this problem the rice was first fried in heated oil for a few minutes and then partially cooked, which led to a slightly finer product but over time it still lost a lot of moisture. It was found that by rinsing excess starch off the rice the product improved, but only marginally.

Yellow rice was prepared by adding tumeric and raisins to the fried and partially cooked rice and then packed and processed. The yellow colour from the tumeric hid the colour formed by the process, but the other problems as mentioned above were still relevent.

A stir fried rice dish and savoury rice dishes (both white and yellow) where the rice was cooked as above with blanched vegetables (diced carrots, peas) and cooked vegetables (onions, mushrooms, and bean sprouts) and spices were also tried. Here it was found that the colour change in the white rice was masked, but the texture of the rice was still mushy. The vegetables became limp and dull in colour after the process and the overall appearance of the product was not very appetizing. The bean sprouts were later removed from the product list because of excessive limpness.

Wheat was partially cooked, but this also led to a slightly gritty type product. It was used in a stir-fry as mentioned above, but the contrast between the slightly gritty firm wheat and the very limp vegetables was not acceptable.

The kidney beans were cooked for 2 to 3 hours, washed with cold water and then chilled and processed. The beans were slightly gritty but were the most acceptable of all the different starches tested. They also did not lose moisture during the process. Problems were experienced in obtaining large quantities of dried beans of a consistent quality and size. At one stage beans could only be obtained that appeared slightly green after processing or where the veins in the skin of the beans turned black. This product was therefore not acceptable because the quality of the raw product could not be guaranteed.

The maize meal porridge was extremely slushy after processing and lost its total consistency. Here, as with the sweetcorn, a burnt taste developed. It was subsequently found that the freezing broke down the structure of the porridge and, after freezing, water could be forced out of the porridge by pressing a ball of it in the hand. Because of the problems with freezing this product was not investigated further.

Blanched sliced, frozen sweet potatoes were packed, frozen and irradiated, but after processing the product was totally mushy and unacceptable.

3.4. Ethnic meals

As has been discussed earlier, although the meat and poultry dishes had been very successful, the starch and vegetable processing was less acceptable. As a result these components of Kosher meals were re-evaluated.

Members of the Catering Corp of the Army tasted these and decided that, within the context of the provision, they were acceptable. At this stage only 6 months worth of data were available. Where accepted, these starches and vegetables with an initial shelf-life of only 6 months were tried, with the understanding that an extension to increase it to 2 years would be the target. After the first year it was found that vegetables and starches could be guaranteed for 9 months, after which they became sensorially unacceptable mostly due to texture defects.

The production of shelf stable meat dishes with a shelf-life of 2 years and vegetables with a shelf-life of 6 months was begun. The list was as follows:

Meat Dishes	**Starches**	**Vegetables**
Meat loaf	Stir-fry rice	Peas
Smoked viennas	Maize meal porridge	Tomato & onion mix
Roast chicken	Sweet potatoes	Baby carrots
Country sausage	Kidney beans	Baby carróts & peas
Beef curry	Yellow rice	Cabbage
Chicken and tomato	White rice	Mixed vegetables
Chicken casserole	Savoury white rice	Sweetcorn
Bobotie	Stir-fry wheat	
Beef steak in gravy	Savoury yellow rice	
Chicken stew		
Smoked chicken		
Beorewors		
Steak		
Meat balls		
Chicken curry		
Beef stew		
Roast beef		
Hamburgers		

Since the shelf-life of the various items differed, it was decided not to pack a full meal in a compartmentalised mealtray, but to pack the menu items separately in the flexible vacuum pouches described in (2.1). Items of varying age could then be used simultaneously.

3.5. Sauces

Depending on the new results obtained by Louw, vegetable dishes that need a thickening agent can again be investigated. At the time that further vegetable work ceased, the lack of stable thickener was the major problem to the development of shelf stable vegetable dishes. Once a stable thickener is available this work can be continued.

4. DISCUSSION AND CONCLUSIONS

4.1 Meat and poultry components

All the products listed in 3.1 have been produced by AEC on a semi-commercial basis for the last 7 to 8 years. These were supplied to the SADF and outdoor enthusiasts on a special permit provided by the South African Department of Health and Population Development. Semi-continuous optimization of the recipes has taken place throughout this time. The supply of these products is available on order.

4.2. Fish

No progress has been made in developing components in this area although successful processing of shellfish (shrimp) has been reported elsewhere.

4.3. Starches and vegetables

4.3.1. Vegetables

The results were disappointing and more must be done to consolidate vegetable processing other than as inclusions in meat dishes such as stews.

4.3.2. Starches

Irradiated starch based products were not successful. If the Kosher project had not been terminated the starches would have been refused within the first few months. This area of work needs a major review.

4.4. Ethnic meals

When the Kosher contract was signed by the AEC and the Army it was to supply 300 men with 3 meals per day for 3 years. This figure was derived from the number of registered Jews in the Army at that time. For the first year AEC supplied Kosher food in these quantities. During the second year of the contract, the troops had by now become aware of this system to send them out wherever required and, therefore, only six of them registered as "Kosher" Jews. AEC were, therefore producing far too much Kosher food. Hence the work and programme of development was discontinued.

4.5. Sauces

Work is still under way by Louw[1] at CSIR but no interim results are available.

5. SUMMARY

The meat products have been of exceptionally high quality and good taste and texture, although optimization of some of the sauces is still required. Any research work in the field of the meat dishes would therefore concentrate on recipe formulation, optimization and selection of thickeners used.

It is possible to produce some shelf-stable vegetables, but on the whole they are not very appetizing in appearance and taste and are fairly expensive due to the process. It is therefore possible to buy canned vegetables of equivalent or better quality at roughly a third of the price. However, vegetable dishes could possibly be investigated, since being value added products the price is not such a problem.

In summary, except for the kidney beans, none of the starches tested were acceptable, mostly because of the damage done by the freezing and the subsequent moisture loss. All of them were edible but not palatable and the cost of the process and packaging was again a major stumbling block in contrast with the meat where the raw product is already a much higher priced commodity and can therefore absorb the process costs.

Finally, a number of successful products are available now for use by interested parties. Some components need refinement and others a major research initiative. The direction and scope of work will be dictated by customer needs and investment available.

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Appendix C

PROCESS OF PRODUCING SHELF-STABLE, IRRADIATED FOODS

The key steps in the production of these items are the following:

1. Precook raw meat, poultry and seafood items to a "medium done" state (internal temperature of approximately 75°C) to inactivate degradative tissue enzymes unless the item is normally thermally processed before-hand (e.g. hot-smoked ham, corned beef, pastrami).

2. Hermetically vacuum seal in individual multi-layer aluminum foil barrier pouches, such as developed by the US Army programme and approved by the US Food and Drug Administration (FDA), or equivalent.

3. Cryogenically or mechanically freeze the pouches of product to around -40°C and irradiate while in the hard-frozen state to maintain eating/nutritional quality. Overlaying packages/cartons with dry ice is an effective and inexpensive way of maintaining the hard frozen state during lengthy gamma irradiation

   For gamma or X ray irradiation, pack individual frozen pouches in shipping cartons and frozen-store or keep under dry ice prior to irradiation. For irradiation times in excess of an hour a layer of dry ice should be placed over and around each carton to maintain the hard frozen state during irradiation. Even at the maximum energy of 10 MeV, electron beam irradiation (which has low penetration) must be applied to each individual frozen pouch; for example, pouches lying flat on a belt carrying them under the electron beam. Pouches thicker than a few centimeters should be irradiated on each side (two-pass, 50% of total minimum dose to each pass) for uniformity. Electron beam irradiation dose rates are normally so high as to not require active maintenance of the frozen state during irradiation (i.e. the exposure time is normally too brief to allow significant warming).

4. Irradiate to the prescribed minimum dose (ca. 25–45 kGy depending on the product) to provide a 10^{-12} level of anti-botulinum sterility assurance employing appropriate dosimetry. Required minimum doses for various products have been determined by *C. botulinum* inoculated pack studies done under the US Army programme (see Microbiological Safety section). At these minimum dose levels the products are microbiologically sterile and can be stored for years under any ambient conditions since endogenous enzymes that would degrade the products over time in the absence of viable microorganisms have been heat-inactivated prior to packaging and irradiation.

5. Immediately following irradiation allow the product(s) to warm up to ambient temperature. Pack individually electron-irradiated pouches in shipping cartons, as with gamma and X ray irradiated pouches before irradiation of the filled cartons.

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