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Effects of irradiation on the rate of water vapor transmission of food packaging materials

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EFFECTS OF IRRADIATION ON THE RATE OF WATER VAPOR TRANSMISSION OF FOOD PACKAGING MATERIALS

BY

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Certificate of Approval--Master's Thesis

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

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ABSTRACT

Food can be preserved by irradiation which is the exposure of food to ionising radiation, high energy electron from electron beams or X-rays or gamma rays from Cobalt-60 or Cesium-137 radioisotopes. Irradiation does not leave a residue in the food and it does not make it radioactive. The low level energy levels of Cobalt and Cesium isotopic gamma rays does not induce any radioactivity. Irradiation has the same preservative effect on food as heat treatment, but because irradiation does not appreciably raise the temperature of the food, it is known as 'cold sterilization'.

Irradiation can potentially be used to preserve fresh meat, poultry, sea food, vegetables, fruits, grain and other foods which harbor disease causing microorganisms and also extend shelf-life. Other potential advantages include replacement of chemical fumigation to control insect infestation of grains, cereals, flour, fruits and vegetables, and partial replacement of food additives such as nitrite in cured meat.

One of the characteristic advantages of the irradiation process is that the product can be irradiated after it has been placed within its container, and sealed so that recontamination after processing is prevented. It is not possible for the product itself to become radioactive, and there are no residue of any kind left by the process. Once treated, foods are ready for use or consumption.

Irradiation can cause changes in the physical properties of some packaging materials which alters the strength, color, sealability, or barrier properties of the materials hence this study was to confirm the effects of irradiation on the rate of water vapor transmission of the food packaging materials selected for the test.

Table of Contents

List of Tables

List of Figures

1. Introduction

Preservation can be identified as a process by which foods are treated to retard decay , spoilage, and adverse changes and to impart a shelf-life to the processed food. There are many reasons for preserving foods. Several plant foods are harvested only once a year. In order to have a supply of these foods without any losses due to spoilage and decay throughout the year, preservation is necessary. In case of a crop failure due to natural disaster or man made disasters, the preservation of previously produced excess food becomes very essential.

With preservation one can obtain a more varied diet, both from the aspect that a crop can be used throughout the year and that crops native to only a small area can be transported and used anywhere in the world. Preservation allows the holding of foods so that they can be used as ingredients for mixed foods. Many of our convenience foods are combinations of various foods. The most commonly used food preservation methods by the food industry today are: heat processing, refrigeration, reduction of available water, preservation by chemical means, control of the package atmosphere, curing and smoking, fermentation, and irradiation.

Until recently, most food companies have used cheaper chemical alternatives to irradiation as a method of preservation and have largely ignored the technology. An initial user was National Aeronautics and Space Administration (NASA). Almost from the beginning our astronauts have been fed food preserved by irradiation. Hospitals have used irradiation as way to serve germ-free meals to patients whose immune systems have impaired. The AIDS epidemic has accelerated this use.

Ethylene dibromide which was used in fumigating grains, fruits,and vegetables, was one of the cheaper alternatives food companies had until Food and Drug Administration (FDA) banned it as a carcinogen. Ethylene dibromide was replaced by methylbromide. Now this too is suspected of being carcinogenic, and now it is expected irradiation could take the place of chemicals as it leaves no residues and is found to besafe.

Post harvest disinfestation and preservation of foods is not something the society can do without (Servaas, 1988). In the Third World where neither chemicals nor irradiation is used, almost 40-45% of harvest is lost to spoilage and pests (IEEE Spectrum, 1984). Success in handling foods after harvest to increase yields and reduce the world hunger is a major goal of U.N. agencies like Food and Agricultural Organization (FAO)and World Health Organization (WHO). Widespread use of radiation as a pretreatment could halt billions of tons, and dollars in food spoilage and disease caused, and low level radiation becomes an important weapon in fighting against hunger (Yost, 1984).

Development of the process of preserving foods by use of nuclear radiation represents a highly concerted effort. The radiation preservation process involves exposing food to electrons or gamma rays. There is a rise in temperature of only few degrees, so the food itself is not cooked in the process: raw foods remain raw. Different effects are obtained, depending on the level of radiation dosage provided (Mehrlich and Siu, 1966). The foods which respond well to exposure to ionizing energy undergo, using the best technology, minimal changes in texture, flavor, odor, color, taste, and nutritional quality. Even at the high doses used to obtain shelf - stable products, these foods closely approach in organoleptic and nutritional quality their counterpart non irradiated foods when prepared for eating. The advantage of the process is that a consumer could put freshlike food on the plate on land, on and under the ocean, in the air and in outer space (Josephson, 1984).

At the lowest levels (in the range of 7,500 rads) sprouting of potatoes and onions is inhibited, extending their post-harvest storage life well into the next harvest. At slightly higher levels, human pathogens like trichinosis-causing worms and liver flukes are destroyed, making infested pork and fish safe for human consumption. At still higher levels, insects larvae and eggs are destroyed, eliminating insect damage in packaged cereal and permitting transport of previously infested fruits across quarantine barriers. At even higher levels, pathogenic bacteria like salmonella, which causes intestinal illnesses, are inactivated. This is reported to cost the U.S. $1.2 billion in medical bills. At the highest levels, in the range of 4.5 megarads, all bacteria are killed and prepackaged food can be kept without bacterial spoilage in the absence of refrigeration.

It has been established that gamma irradiation from Cobalt 60 or Cesium 137 does not induce radioactivity in foods exposed to it. It has been noted that foods irradiated with Cobalt 60 and found to be wholesome are also wholesome when preserved by electrons at energies up to 10 Mev (a measure of electrical energy equivalent to an electron with a million volts).There is theoretical potential that electrons at sufficiently higher energies may induce a degree of radioactivity in treated foods. The thresholds of activation lies in the range from 10 to 16Mev (Mehrlich and Siu, 1966). The upper limits are 5 Mev for X rays and gamma rays and 10 Mev for accelerated electrons (Giddings, 1986). The main source is the radionucle Cobalt 60 (^{60}Co) which emits gamma rays up to energy of 1.33

Mev (Egan and Wills, 1985). The average dose is determined by the thickness of product which can be penetrated and preserved by electrons.

According to theoretical calculations a person might receive an added level of total body irradiation amounting to 0.26 milliroentgen (Mr) per year if his entire diet were irradiated with electrons at an energy level of 24 Mev, and if the food were ingested immediately following irradiation. This compares to 150 Mr per year which people in general receive from naturally occurring radioisotopes in their normal non irradiated foods (Mehrlich and Siu, 1966).

Irradiation makes a smaller contribution to radioactivity in food than do natural isotopes. The natural activity in meat for example, amounts to about 100 becquerels, or 100 radioactive "disintegrations" a second. A dose of radiation that would completely sterilize meat could induce 10 becqerels of radioactivity. In addition, most of the radioactivity induced in food by irradiation decays by the time someone eats it. Irradiated food spends more time in storage than fresh food, allowing its natural and induced radioactivity to decay. So an irradiated food meal could actually be 15 to 30% less radioactive than a fresh one, depending on the food and the time it spends in storage (Sonsino, 1987).

Society has been consuming foods treated and preserved by chemicals, sprays, and preservatives, and also believes when the food looks fresh and smells better it is not a carrier of diseases. In the countries where irradiation is accepted, the initial consumer response has been negative, but when consumers realized the advantages of irradiation over preservatives and chemicals, they started gradually changing their attitudes and accepted this process (Bruhn, Schutz, and Sommer, 1986). Hence, consumer education is vital to make food irradiation a reality in the U.S. The practical uses of irradiation in improving the availability of selected fruits, vegetables, meat and meat products as well as sea foods appear within sight. And the benefit is reducing the diseases caused by deadly pathogens and bacteria such as salmonella and C.botulinum.

1.1. Use of irradiation in medical products

Pressure from the Environmental Protection Agency and the health insurance industry to cut health care costs, have motivated medical products packagers to look into a new sterilizing method utilizing gamma radiation. Gamma rays effectively kill bacteria, often at lower cost than ethylene oxide (EtO), is a useful sterilization means for large volume products. But gamma rays can discolor or degrade many plastics. Since the recent introduction of radiation resistant grades of common plastic materials, radiation sterilization has gained wide acceptance. Gamma radiation is expected to capture 80% of the 440 millions lbs/year market of disposable plastic medical products by 1990.

EtO sterilization will not be completely replaced because certain products, including iodine, lydocaine, lubricating jelly and alcohol are incompatible with radiation. The movement for future package designs for dry products (disposable devices) seems to have potential for radiation sterilizable.

Competitive cost is helping the growth of radiation sterilization. For large volumes, radiation costs less than EtO sterilization. Cost depends on product density, dosage level, and product volume. For example, a container load of product (2000 cubic feet) with density of 0.15g/cc sterilized with a 1.5 megarad dose would cost about 60 cents/cubic foot and at 2.5 megarads it would cost about $1.00/cubic foot. EtO sterilization costs range from 90 cents to $1.20/cubic foot (Lodge, 1987). Availability of more radiation facilities has helped to reduce the cost. The cost savings can largely attributed to the elimination of sterility test costs, quarantine inventory costs, and process rework costs (Gammagram, #5).

Manufacturers of medical products stand to gain a number of significant benefits from the use of gamma sterilization. Economy, better control, less package stress and increased efficiency of kill are major advantages that are immediately realized .

Gamma rays penetrate every position of the product and its package, whereas EtO gas and steam are surface sterilants. Both can effectively kill microorganisms that exist on the surface of the product, but they have almost no effect on microorganisms that reside within sealed cavities. Both EtO gas and steam sterilization require drawing a vacuum and the introduction of a high positive pressure. Potentially, both forces exert stress on packaging materials and their seals. With gamma sterilization, these stresses do not occur.

1.2. Sterilization

Sterilization can be defined as the process by which living organisms are removed or killed to the extent, that they are no longer detectable in standard culture media in which they have previously been found to proliferate. This concept conveys the idea that the biological procedures used to assay sterility can be as important as the process used to achieve this condition. the specific factors regulating the selection of a sterilizing process for a given product, is depended on the nature of the product, the effect of sterilization on the product, legal acceptability or requirements for a product treated by a particular process, economics of the sterilizing process, and the parameters of sterility assurance tests for each sterilizing procedure (Brunch, 1972). Each sterilization process has its own advantages and disadvantages and also package requirements.

1.2.1. Steam Sterilization

The most dependable and universally standard procedure for the destruction of all forms of microbial life is the application of moist heat. Steam sterilization is heating in an autoclave utilizing saturated steam under pressure at a minimum of 121°c for minimum of 15 minutes. This time is measured after the temperature of the material being sterilized reaches 121°c. One might expect that a process as rigorous and widely used as steam sterilization would not regularly require monitoring, since the physical controls used in the process consisting of pressure gauges, thermometers, thermocouples and various other devices that are capable of indicating minimum and maximum variations in the physical parameters, to indicate sterilizer performance. Tragic accidents from inadequate sterilization of articles stand as evidence to the failure of these controls alone for efficiently monitoring steam sterilization on a consistently positive basis. Sterilization is performed to terminate a biological process hence a biological (rather than a mechanical) system is required to confirm that sterilization has taken place. Steam sterilization also needs post-sterilization treatment: the sterilized products have to be dried before they go through a quarantine period of 7-14 days.

1.2.2. Ethylene oxide sterilization

Gas sterilization has been recommended only when other methods cannot be used. Radiation sterilization is considered more reliable than gas, however EtO has found far reaching applications particularly for the sterilization of many disposable medical devices made from plastics, textiles, glass, rubber, and metal construction. Sterilization with EtO requires proper control of temperature, humidity, gas concentration, time of exposure, and a significant knowledge of the physical and chemical characteristics of the materials being sterilized, including the packaging materials. All of these variables influence the rate of destruction of microorganisms under experimental conditions. In large scale sterilization with EtO, constant controls of these variables and the reliability of the penetration of gas and water vapor into remote segments of the articles being treated is the greatest concern. The control measures need to be stringent and extensive to achieve sterility rather than decontamination. Complete monitoring and integration of all physical variables is essential, but the routine use of appropriate biological indicators perhaps is more critical in this case than with any other process. Gas sterilization, like steam sterilization requires post-sterilization treatment: the sterilized product has to be aerated to remove toxic residues before the products go into a quarantine period of 7-14 days.

Whenever EtO is held in presence of H_2O (liquid or vapor), the major degradation product is ethylene glycol (ETG, $C_2H_6O_2$). Also EtO reacts with chloride ions in the presence of moisture in foods and polymeric materials to form ethylene chlorohydrin (ETCH), a non-volatile, toxic substance which led to a reevaluation of the types of residues and potential hazards from the use of EtO on foods, drugs, and medical devices (Bruch, 1972). Studies performed with human subjects and experimental animals verified EtO's potential for toxicity, carcinogenicity, and mutagenicity (Gammagram # 4).

1.2.3. Radiation Sterilization

Gamma rays are pure energy , similar in may ways to microwaves and x-rays. There is no radioactivity imparted or residues created. This can be compared to the potentially harmful residuals with EtO gas process (Gammagram, #2). Radiation sterilization involves application of sufficient ionizing energy to render an article free of viable microorganisms, and when protected from recontamination, the irradiated article remains free of organisms regardless of duration or conditions of storage. Ionizing energy exerts its lethal effects on microorganisms both directly and indirectly. Direct action is based on the target organisms being hit by an ionizing particle or ray. Microorganisms can be destroyed by direct hits. This involves a probability concept that depends on the number of particles or rays, or the dosage, and the number of targets. The rate of destruction of the microorganisms can be influenced only by the dose or the number of ionizing particles. Ionizing energy also exerts its lethal effects by indirect actions. Free radicals and reactive compounds are formed which are sidle to organisms. The medium, temperature, concentration of the solutes, pH, and the gaseous environment all have an important effect on indirect action.

Radiation sterilization is most often employed as a continuous process during which the materials to be sterilized are exposed to a radiation source, sufficient to absorb a predetermined dose of ionizing energy, usually 2.5mrads or more. The positive effect of radiation in sterilizing medical devices and other articles in their hermetically sealed packages, is direct and uncomplicated. Unlike the other sterilizing methods irradiated products do not require any post-sterilization treatments and also quarantine could be eliminated (Macek, 1972).

The process variables involved in the different sterilization processes are summarized in Table. 1.

Table. 1. Different Process Variables

Steam	Ethylene oxide	Gamma radiation
Vacuum	Vacuum	Time
Pressure	Pressure	
Temperature	Temperature	
Relative Humidity	Relative Humidity	
Time	Time	
	Gas Concentration	

The key to gamma sterilization is reliability and its simplicity. Gamma sterilization has only one variable which requires close control and that is time (Gammagram,#2).

The major reason for the rapid change in industry to this more reliable process is the cost. The economics of large scale operations and the acceptance by the Food and Drug Administration (FDA) of the dosimetric release procedure have significantly reduce the cost of gamma sterilization.

The results of an increasing number of reports corroborating the mutagenic and carcinogenic effects of EtO have also contributed to the switch to gamma sterilization. Concern over the well-being of their employees and the increased cost necessary to meet the continuing tighter control regulations being imposed on the EtO process have caused manufacturers to reevaluate their processes, where it has shown that radiation is more reliable and economical. Gamma-processed materials can be used immediately, since there is no residue generated by radiation. Gamma rays, like light photons, have no mass and therefore cannot induce radioactivity on materials, and there has never been a reported toxic reaction to any sterilized plastics materials resulting from gamma process (Gammagram # 5).

As practical experience with gamma sterilization has extended throughout the medical industry, so has the knowledge of and confidence in its many advantages.

Gamma sterilization is a highly penetrating sterilant: no area of the device and container, even its core, is left with uncertain sterility. Even high density products such as prefilled humidifiers can be readily processed and used with confidence. Packaging remains intact with gamma processing. Since there is no requirement for pressure or vacuum, seals are not disturbed, and no special permeability requirements need to be met. Gamma processing is a reliable procedure. There is only one variable to control-- time. With only one variable to control, the possibility of error is reduced to minimum (Gammagram, #4).

1.2.4. Package requirements

Selecting a suitable material for the sterilization method to be used is very important as each process has its own limitations: the steam process needs adequate air and moisture permeability in the packaging material. Because of the high temperature involved, many thermoplastics materials cannot be used; only high density polyethylene (HDPE), Polypropylene (PP) and nylon are suitable. Medical grade paper is the most widely used porous material for sterilization and it is often used along with a heat-resistant plastics material.

The gas process does not restrict the use of thermoplastics materials because it is carried out at low temperature, but porosity of the packaging material is an important factor. Most gas processes involve vacuum cycles which impart considerable physical stresses on the package if entrapped air in the package is not easily removed. As there is no standard gas process in use, it is important that packaging materials be selected and tested in the cycle for which it is intended.

Radiation sterilization offers the widest choices of packaging materials; high temperatures are not involved so that many thermoplastics materials can be used, and since radiation penetrates all common packaging materials, the permeability factors associated with steam and gas sterilization processes are not relevant. Some materials such as polypropylene (PP), polyvinyl chloride (PVC) may lose strength and/or discolor; however, radiation resistant grades of these materials are available, so this may not create a major issue (Powell, 1972).Since the approval of gamma radiation by the World Health Organization (WHO) several European countries have given go ahead for irradiation to be used on foods (Kimber, 1985). The use of ionizing radiation is increasing not only in medical product packaging but also in the food industry. This has led the scientists to study in detail the effects of radiation not only on the foods but also the packaging materials that the products are packaged in. As there is no heat, pressure, or vacuum involved in the ionizing sterilization method and for the safety of food from being recontamination it is best irradiated with in the package. The effects of radiation on the packaging materials and how they perform after the product is packaged and put on shelves, has become an important consideration, not only to preserve the food longer but also to prevent any possible chance of recontamination through weak seals or changes in barrier properties after the ionizing treatment.

1.3. Effects of irradiation on food

Irradiation can substantially reduce or even eliminate viable microorganisms and insects which are responsible for deterioration and losses in food during storage and in this way such losses may be greatly reduced. The liability of food to suffer deterioration is not the same in different parts of the world and so the potential value of irradiation in preventing food spoilage may vary from one country to another. For example, the loss in stored grains resulting from infestation with insects, in many countries, is sufficiently great to warrant the use of irradiation for infestation, but this is not necessarily so in all countries. The dose of radiation for disinfestation needed for such a treatment is relatively low. Provided the process is adequately controlled, no possible hazard to health can be foreseen and it has been permitted in many countries with the approval of the World health organization (WHO). Even though the loss of grain which results from infestation may be small in certain countries, irradiation is desirable in order to limit the spread of insects from one country to another. In those parts of the world where the transport of food is difficult and where refrigerated storage for food is scarce or nonexistent, the use of radiation may facilitate wider distribution of food than would otherwise be feasible; in this way a more varied and possibly nutritionally superior diet may become available to the inhabitants. In countries where facilities for the transport and refrigerated storage of foods are well developed, irradiation of food may make feasible cheaper methods of transport and storage; in this way the cost of food to the consumer may be significantly lowered. A prolongation of the storage life of seasonal crops, for example soft fruits may be of advantage, particularly from the economic standpoint.

Deterioration of some vegetables during storage can result from the breaking of dormancy and the growth of shoots or sprouts. Such changes can be inhibited by irradiation, with substantial prolongation of the storage life. Inhibition of the maturation of some fruits, with similar beneficial consequences, can also be brought about by irradiation.

Certain foods are liable to be contaminated with pathogenic organisms. Suitable treatment by irradiation may reduce or eliminate such organisms. Examples of processes of this type which are already known to be technically feasible are the elimination of salmonella and Trichinella spiralis from meat and meat products. When such pathogenic organisms are liable to be present in food which may be distributed throughout the world, irradiation of the food appears to be one method by which the spread of pathogenic organisms could be greatly reduced.

Microbial contamination of an ingredient used in the manufacture of compounded foods may result in the product having poor keeping qualities or even containing pathogenic organisms. Certain spices are contaminated with bacteria which can not grow on the spices itself but which profilerate in the food to which the spice is added. By treatment with radiation the contaminating microorganisms can be killed or their numbers reduced to such a low level that the problem is no longer serious.

Many essential nutrients in foods, particularly certain of the vitamins, are destroyed to some extent when a food is irradiated. The magnitude of such losses will depend on many factors, including radiation dose, environment during irradiation, and post irradiation storage conditions. Although there are many differences in the sensitivity of individual vitamins toward heat and radiation, the losses resulting from the application of the highest doses of radiation at present under consideration for food preservation are in general broadly comparable with those induced by thermal processes. However, little evidence is at present available concerning the extent to which the destructive effects of irradiation and domestic cooking procedures may be additive. Nevertheless, when diet consists of mixture of many food items it seems unlikely that the nutritional value will be lowered by widespread consumption of food processed by thermal methods. The effects of ionizing radiation on food components other than the vitamins is generally quite small. It is possible that there may be a slight reduction in the nutritive value of certain of these food components, but the change is unlikely to be large enough to be of significance in human nutrition. The importance of the loss in any essential nutrient should be assessed in the light of the contribution made by the irradiated food item in providing the normal requirement of that nutrient (FAO, and WHO, 1964). Ionization radiation is used as a disinfestation of food products such as grains, groats, dried fruits and vegetables, and dry concentrates. As insect damages alone cause heavy losses to the governments annually. Therefore there is great need for good disinfestation methods against the insects, they are not safe, as the use of chemicals and fumigants leave enough residues, which is impossible to remove and also have adverse effects on the health of the consumer. Irradiation of the grains is a very effective method of killing insects, which leaves no residues, and there is no necessity of unpackaging and packaging it again, as it could irradiated with the container itself. Irradiation of grain to 11-18 Krads completely destroys the pests and allows the grains to be stored for at least four months without damage or deterioration in quality.

1.3.1. Meat

An increase of even a few days in the shelf-life of meat and meat products has great economic value. This is especially important when meat is and meat products must be transported to long distances by land or sea. At present, both ordinary refrigeration and dry ice storage are used in transporting them. It is also possible to freeze the meat and transport it in the frozen stage, but it lowers the quality of the product, and losses are greater on defrosting.

Irradiation of fresh meats, makes it possible to increase the storage time to about six months without being frozen, which allows to be transported (Metlitskii, Rogachev, and Krushchev, 1968). And the Table. 2., shows how long the storage of other meat and meat products is extended. The use of irradiation has the potential to increase the storage life and reduce the public health hazards associated with meats. The first application of this technique to flesh foods is likely to be the improvement of the microbiological quality of the meat and allow for adequate storage life extension, so that meat could be exported overseas (Egan and Wills, 1985).

TABLE. 2. Effects of Radiation on the Preservation of Meat and Meat Products

PRODUCT	IRRADIATION DOSAGE (MRAD)	STORAGE TEMPERATURE CONDITION °F	STORAGE(DAYS) BEFORE	AFTER
MEAT- CARCASS	0.5	38	-----	180
PORK-RAW	0.9	36 - 41	-----	120
LAMB-CARCASS	0.4	34	-----	56
BEEF-CARCASS	0.4	34	-----	70
BEEF-CUT IN PIECES	0.9	41	-----	660
GROUND-BEEF	0.9	41	-----	84
BEEF STEAK RAW	0.5	41	7-10	56
PORK CHOPS RAW	0.5	41	7-10	56
RABBIT MEAT RAW	0.5-0.6	41	7-10	56
CHICKEN RAW	0.5-0.6	41	7-10	56
VIENNA SAUSAGES	0.5	34	21	70
		50	10	37
		59	7	24
	0.9	36 - 41	----	98
EVISCERATED CHICKEN	0.4-0.6	34	10	34
		38	7	21
		50	6	11

Source: Food irradiation progress outside the U.S., 1968

1.3.2. Seafoods

Decreasing the losses of fresh seafoods is of great economic values too. Shelf-life of irradiated seafoods could extended as shown in Table. 3. As extended shelf-life would allow time for the distribution of the products over longer distances without any spoilage which would result in making available of seafoods, to areas remote from harvesting areas (Metlitskii, Rogachev, and Krushchev, 1968).

Table. 3. Effects of Radiation on the Preservation of Sea Foods

PRODUCT	IRRADIATION KRADS	STORAGE TIME, (DAYS) UNIRRADIATED	IRRADIATED
FLOUNDER RAW, FRESH	500	3-4	23-24
CODFISH FILLET, FRESH	250	7-9	35-37
SALMON FILLET, FRESH	150	3-4	20
SOLE, FRESH	250	3-4	20
HADDOCK,FRESH	600	5-7	30-40
POLLOCK, FRESH	600	7-10	30
CRAB MEAT RAW	500	3	50
CRAB MEAT BOILED	400	4	60
OYSTERS BLANCHED	500	7-9	60
MOLLUSK MEAT	450	14	119
SHRIMP CLEANED AND BOILED	250-450	4-16	19-110

Source: Food irradiation progress outside the U.S., 1968

1.3.3. Vegetables and fruits

Irradiation of vegetables and fruits, can extend the shelf-life products and allows seasonal products to be available all through the year. It also can inhibit cell division and sprout development, in tubers and bulbs, for example, irradiated potatoes could be stored for nine months without any development of sprouts, and onions would stay fresh for sixteen months (Food irradiation, 1984). The possible use of irradiation for extending fruit shelf-life by delaying ripening can be very important in the marketing of fruits that are highly perishable because of rapid physiological changes. Retarding ripening of some of these fruits by irradiation may be of limited use in the U.S. where there are good refrigeration facilities, but in some of the less developed countries the application could prove beneficial. In fruits it not only delays the ripening process but also kills the spoilage organisms and extend shelf-life (Dennison, 1967). Table. 4 and 5 show few vegetables and fruits respectively, how long their shelf-life could be extended.

TABLE. 4. Effects of Radiation on the Preservation of Vegetables

PRODUCT	IRRADIATION DOSAGE (KRAD)	STORAGE TEMPERATURE CONDITION °F	STORAGE(DAYS) BEFORE	AFTER
Fresh Poi	750	70-80	1-2	7
Mushrooms	20-50	32-40	5-7	10-14
Tomatoes	400-500	20-30	5-7	18-21
Ginger	2-4	70-75	14-21	84-112
Potatoes	10	70-75	60-90	270
Onions	6	70-75	60-90	480
Plantains	10-20	68	10-13	20-26

Source: Food irradiation progress outside the U.S., 1968

Table. 5. Effects of Radiation on the Preservation of Fruits

PRODUCT	IRRADIATION DOSAGE (KRAD)	STORAGE TEMPERATURE CONDITION °F	STORAGE(DAYS) BEFORE	AFTER
Papaya	75-100	70-75	7-14	10-18
Mangoes	90-120	48	4-7	10-14
Pineapple	40-50	45-48	10-14	14-21
Peaches	150-225	3-5	8-10	14-21
Strawberries	100	75	6-7	20
Blue berries	200	38	13	27
Sweet cherries	200	32-35	14-18	15-20
Oranges	150-300	35-50	14-18	49-63
Banana	40	68	21	27
Grapefruit	150	50	16-20	49-63

Source: Food irradiation progress outside the U.S., 1968

The value of ionizing radiation for food preservation arises from its ability to destroy the microorganisms and insects which cause food spoilage and deterioration. An advantage that irradiation offers is that it leads to little, if any, rise in the temperature of food during treatment. The use of radiation thus opens up the possibility of a wider distribution of perishable foodstuffs in the fresh or near-fresh state.

Radiation is also effective in controlling insects and can be used in combination with other methods for the preservation of foods, such as refrigeration, heating, curing, and additional of chemical substances.

By the use of radiation process, the storage life of food products could be extended very considerably at both normal temperature and under refrigeration; proper packaging which will prevent recontamination is required and such materials as plastics, as well as the more conventional rigid containers can be used. The method is, therefore, well adapted to the present trend toward the distribution of packaged food products and mechanization in the food industry.

Many of the actual or potential uses of radiation as preservation method are shown in Tables. 2, 3, 4 and 5. Irradiation offers valuable addition to the existing methods of food preservation and its use can significantly increase the total amount of food available in the world by helping to reduce the serious losses that occur at all stages between the production of the food products and their consumption. In addition, it can provide an important new means of helping to reduce the incidence of communicable disease transmitted through food (FAO and WHO, 1964).

Many of the deteriorations that occur in the packaged foods are associated with gain or loss of water vapor. Moisture exchange with surroundings can cause physical changes, alter flavors and promote mold and bacterial growth. Particularly in irradiated packaged foods where radiation is used to kill or reduce viable microorganisms and if the packaging material undergoes any changes due to radiation and allow the food to be contaminated the entire purpose of radiating the food is lost.

1.4. Objective

In order that the objective of the radiation treatment be fulfilled, it is essential that the irradiated food not subsequently become recontaminated. To avoid recontamination, food is normally packaged in sealed containers before it is irradiated. The materials used for packaging must withstand the effects of irradiation and the hazards of handling and storage. Some flexible packages are less effective in preventing recontamination than is commonly believed; the material may crack or develop pinholes, or the seams may fail.

Where such methods of flexible packaging are proposed for use, extensive tests of the integrity and durability of the packages will be needed.

This study is to confirm the effects of irradiation on the rate of water vapor transmission of the ten different packaging materials selected.

2. Significance of Package Requirements for Irradiated Products.

This study investigates the following hypothesis: radiation causes changes in the rate of water vapor transmission of ten selected packaging materials at levels currently accepted for food processing.

Food treated with ionizing radiation to increase shelf-life, must be packaged to prevent any microbial recontamination. There is no danger that either food or package will become radioactive at the levels of irradiation to be used for food, but irradiation can cause changes in the physical properties of some packaging materials which alters the strength, color, or sealability or permeability of the material.

2.1. Generally observed physical changes

Plastic packaging materials used for foods are synthetic organic materials of high molecular weight, and they are made of a large variable number of repeating monomer units, and may be straight or branched, randomly or regularly. Almost all the materials contain small amounts of other ingredients to impart particular technical properties. These ingredients are normally simple chemicals of low-molecular weight.

All packaging materials are affected by ionizing radiation, the only variable of the type of effect is the dose necessary to produce it. As a result of minor chemical changes, the physical properties of the materials change because of the presence of other organic substances and also owing to their higher molecular weight. Since chemical reactions are taking place in a solid medium, it is difficult to predict the particular behavior. Certain additives have a protective action and can reduce the effect of radiation on the materials. These may be either energy absorbers or chemical reactants which combine with radiation-produced free radicals. The atmosphere in which irradiation takes place often modifies the effects. In particular, differences are usually observed between the behavior in the presence or absence of oxygen. Findings, however are not consistent: with some plastics degradation is enhanced in the presence of air, whereas for others it is reduced. Thin specimens are likely to be more affected because oxygen is freely available. With thick items, the oxidation process, except at very low dose rates; will be diffusion controlled. Post-irradiation effects have been also noted, because of the free radicals in materials following exposure to irradiation.

The observed effects on packaging materials properties are varied, but, most importantly, involve mechanical characteristics. Polymerization and cross linking increase the molecular weight and therefore lower the mobility of molecules and reduce creep. This may raise the tensile strength, depending on the normal mechanism of tensile breaking, and dose increases hardness and brittleness. Impact strength usually decreases or remains relatively unchanged. Radiation-induced degradation, on the other hand, by lowering the molecular weight, detracts from most of the valuable properties associated with plastics. Tensile, impact, and shear strengths are reduced as is the elongation at break. Embrittlement occurs even though the materials may have become somewhat softer. Crystallinity can increase in polymers that undergo scission, causing a rise in density.

An obvious effect of radiation on many packaging materials is the development of color. In some cases, the material will become opaque after prolonged exposure. Most materials turn yellow or brown, but the dose at which discoloration becomes noticeable varies widely. The extent and amount of color development may vary on storage after irradiation, either increasing or diminishing with time, and is usually affected by the presence of oxygen.

Both low and high density polyethylene are resistant to radiation sterilization and can withstand, without substantial changes in mechanical properties, doses up to at least 100Mrads.

Polyethylene in general, cross links on radiation, although there is a chain scission mechanism as well. The average molecular weight increases and crystallinity decreases. The effect on mechanical properties is complex.

For example, the tensile strength first increases with dose up to about 10 Mrads, then decreases slowly, returning to its original value at 100-150 Mrads. The elastic modulus behaves in an opposite manner, first falling, then rising again. Impact strength begins to fall at higher dose rates and reaches the minimum at very high levels of irradiation.

Polypropylene is readily affected by radiation and is borderline in stability. Hence it is one of the more interesting materials for consideration especially as its combination of mechanical properties and barrier properties make polypropylene one of the main polymers for many food and biomedical applications.

Both chain scission and cross linking result from irradiating polypropylene although, in the presence of air, oxidative degradation occurs as well. Cross linking is evidently the major factor at low doses because the impact strength suffers an immediate fall followed by a slow decay over a period of months. Even after 2.5 Mrads, impact strength can decrease eventually by more than 50%. Discoloration also occurs in polypropylene, often noticeable yellow, which, although aesthetically objectionable, may be masked by the incorporation of trace of a different color pigment, usually blue. Because of the radiation sensitivity of polypropylene, the small differences between the products of different manufacturer's and also the various formulations on each manufacturer's range can be important. The changes referred to do not necessarily go together; it could be that a grade which discolors severely does not always embrittle nearly so much in comparison. The purity of the polymer, the stabilizers used, the fabrication process, and shape of the final article all are relevant to suitability for radiation sterilization. Currently, there are some polypropylenes which can withstand radiation sterilization; others are not yet good enough. It is essential to evaluate performance after storage and not merely immediately following exposure.

Polystyrene is the most radiation-stable of common molding plastics, and large doses are required to bring about significant changes. Aromatic rings in the structure appear to provide a protective action towards radiation effects. This can stand doses up to 500 Mrads. The so called high-impact polystyrene is somewhat less stable towards radiation, but nevertheless is still among the more resistant of plastics.

Polyvinylchloride (PVC) can withstand lower dosage of radiation (up to 15 Mrads), both in its plasticized and unplasticized form. Mechanical properties begin to show some changes above 15 Mrads.

In general the PVC crosslinks in the absence of air and degrades if oxygen is available. Hence degradation may be observed upon irradiation of thin films but is confined to the surface of thicker articles. PVC discolors at quite lower doses, (2 to 3 Mrads), the shade and intensity varying with the presence of different plasticizers and stabilizers. It is interesting, that in contrast to the behavior other materials such as polymethyl methacrylate, the discoloration of polyvinylchloride intensifies upon subsequent storage. The inclusion of sodium stearate is reported to be effective in reducing discoloration, whereas, the use of an organotin stabilizer promotes color development. These tin stabilizers also seem to inhibit crosslinking.

Differences have been noted between the effects of radiation on unplasticized and plasticized polyvinylchloride and also compositions containing different plasticizers. A more important effect is the liberation of hydrochloric acid with corresponding production of unsaturation. The effect is reduced by the stabilizers always present in commercial compositions but some hydrochloric acid is available for further reaction

Nylon crosslinks and loses crystallinity upon irradiation causing a slow increase in tensile strength but a much more rapid drop in impact strength. Films and fibers are more affected mechanically than thick moldings possibly because the loss of strength rising from the reduction in crystallinity is more important for thin section materials than the accompanying increase in strength caused by crosslinking. Also the presence of oxygen substantially increases the effects of radiation.

Polyethylene terephthalate is suitable for radiation sterilization, whether in film or fiber form. Mechanically it can withstand at least 100 Mrad, although discoloration occurs at lower doses. Crosslinking is the major effect of radiation but radiation-induced oxidation can be important too, in the presence of air (Plester, 1972).

'Safe for use after radiation' is the primary criterion for packaging materials proposed for use in preservation of foods. When packaging materials are in contact with food, the possibility exists that certain compounds produced as a result of irradiation may contaminate the food. The study which was performed in the U.S. Army Natick laboratories to determine the safety, amount, and nature of extractives, confirms the fact that electron and gamma radiation of plastics films in the presence of food-simulating solvents produced the same chemical compounds but in slightly different amounts. The differences were attributed to the stability of the films with regard to their susceptibility to crosslinking and in some cases degradation at relatively low dose rate for gamma irradiation and higher dose rate for electron beam radiation (Killoran, 1972).

2.2. Significance of Water Vapor Transmission Rate (WVTR) for Food Packaging

The permeability protection requirement of a food depend not only on the susceptibility of the components in the foods to change but also on its expected or required shelf-life prior to consumption.

2.2.1. Meats

In meat products the package is not only intended to prevent bacterial contamination but also development of flavors and odors due to spoilage from bacteria or molds. The principle role of the package is prevention of moisture loss, the exclusion of foreign odors and flavors, and moderations of oxygen transfer. A relative humidity of 85-90% is needed to prevent desiccation, and, unless the package material is a perfect barrier, the atmosphere outside the package should be kept at a relative humidity of 85-90% (Sacharow and Griffin,1980 pp 119 -150).

2.2.2. Seafoods

Fat oxidation reduction, dehydration reduction, elimination of drip, prevention of odor permeation and providing for less bacterial and chemical spoilage are the requirements for a suitable seafood package.

To reduce oxidation of fat, the use of a good oxygen barrier package and cold storage would greatly help. To reduce dehydration, a good water vapor barrier is required. Excess moisture loss leads to texture, flavor, and color changes in seafoods, since they are wet. Bacterial and chemical spoilage in seafoods are caused by enzymes and bacteria present in them. The way to arrest the growth of bacteria and spoilage is to kill the product, and then immediately, gut, wash and freeze the product (Sacharow and Griffin, 1980 pp 209 - 238).

2.2.3. Fruits and Vegetables

Because fruits and vegetables are living organisms even after harvesting, they can remain fresh only as long as normal metabolism continues. Metabolism involves absorption of oxygen which breaks down the carbohydrates in the product to water and carbon dioxide. If the availability of oxygen is restricted, the chemical reaction changes and small quantities of alcohol are produced. This results in off-odors and flavors and a breakdown of plant cells, a series of events called "anaerobic decay" which can spoil fruits or vegetables within few hours.

The more common type of spoilage of fruits and vegetables is that caused by microorganisms such as yeasts,molds, and bacteria. These organisms can cause destruction by growing on the exterior of the product or they may invade the interior through a surface bruise or cut and cause internal decay. This is why careful handling and packaging is so important in the preservation of freshness and quality (Sacharow and Griffin, 1980 pp 239 - 275). As the package has to retain the aroma, it should not allow any gas or vapor to penetrate and deteriorate the product, it should not allow any moisture gain or loss to occur, and also should not allow any spoilage organisms to get into the product.

2.2.4. Cereals

Cereals require protection from moisture, insects, and dust, and when stored in bulk, they should be protected in packages that breathe or else rancid odors tend to accumulate. Milled grain products like wheat, bulgar, seminola, corn, and rye, should be protected from infestation and moisture (Sacharow and Griffin, 1980 pp 403 - 440).

2.2.5. Package Requirements

There are various barrier needs that can be quantified for each item. These are oxygen, carbon dioxide, sulphur dioxide, water/moisture, oil, and volatile organic vapors. These influence the following; the gain of oxygen from ambient air, the loss of carbon dioxide, the loss of moisture (water based foods), the gain of moisture from ambient air (dry foods and oil based products), the loss of ethanol, and resistance to oil migration (Salame, 1974).

Much of the deterioration that occurs in packaged food products is associated with gain or loss of water. Moisture exchange with the surroundings can cause physical changes, alter flavors, and promote mold and bacterial growth.

The specific change which is brought about by the role of water in foods is its being a solvent, a medium in which reaction proceeds,or as a reactant in its own right. It also acts as a means of making structural changes in texture, viscosity, and other properties. The general pattern is for oxidation to be favored at water activities below 0.5, browning over the midrange 0.3 to 0.75, while mold growth and bacterial infection are accelerated by values of water activity over 0.7 and 0.85 respectively. The water activity ranges which food stuffs characteristically exhibit are charted, together with the minimum water activities at which specific microorganisms start growth. The consequence of this link is that packaging may have two roles, depending on the circumstances. In baked products, where the interior may be more moist than the surface crust, the pack should allow the surface to lose water so that water activity there is below that for mold growth. The function of the packaging material is then hygienic, to prevent contamination and soiling. For dry products the role of the packaging material is reversed. The barrier is required to prevent moisture pick-up which can lead to flavor or texture loss, and mold growth. Moisture loss can cause wilting of leaf vegetables,and surfacing hardening of packed cakes. A rise in moisture content can cause expansion and disintegration of food products (Hine, 1987).

2.3. Advantages of using package products

In meat products the package is intended to prevent bacterial recontamination and also prevent development of flavors and odors due to spoilage from bacteria and molds. The main role of the package is the prevention of moisture loss in case of fresh meat and moisture gain in case of process meat products. A good barrier material will prevent absorption of odors and flavors from external sources. Control of oxygen permeation requires a compromise between development of ideal color and prevention of oxidative degradation reactions. Oxygen is needed to keep fresh meat red, but it will promote rancidity, hence moderate oxygen permeability is sought. The package also should be capable of resisting tearing and puncturing from normal handling (Sacharow and Griffin 1980 pp 119-150).

Packaging cannot delay or prevent vegetables from spoilage. Incorrect packaging can accelerate spoilage. However, packaging can serve to protect against contamination, damage, and excess moisture loss. Too much of moisture barrier will cause an excessively high relative humidity in the package and result in accelerated spoilage due to microorganisms, or in skin splitting on some fruits (Sacharow and Griffin 1980 pp 239 - 275).

Seafoods are most perishable of all foods. The extension of shelf life of sea foods is possible if the growth of enzymes and bacteria present in fish could be arrested. A suitable seafoods package should have the following characteristics: reduce fat oxidation, reduce dehydration, provide for less bacterial contamination, eliminate drip, and prevent odor permeation. The maintenance of proper shelf life by packaging becomes an essential prerequisite for marketing seafoods all over the nation (Sacharow and Griffin 1980 pp 209 - 238). Packages, if hermetically intact, will reduce cross contamination from drip.

In cereals, the package should protect the product from insects and moisture absorption. Packages for milled grain products protect against insects and moisture, and increase the keeping quality and extend shelf life (Sacharow and Griffin 1980 pp 403 - 440).

In general, packages for food products extend shelf life, prevent microbial recontamination, chemical changes ,physical damage and present the product to the consumer in the most attractive manner.

3. Irradiation Sterilization Technique

3.1. Ionizing radiation

Radiation displaces electrons (this phenomenon is called ionizing) producing known free radicals (Food Irradiation, 1984). Electrons and photons, whether they come from an accelerator or a radioactive source such as Cobalt-60, constitute a form of energy just like visible light. In fact, they form part of the spectrum of energy which extends from radio waves through the visible spectrum to high energy electrons. This energy is capable of inactivating micro- and other organisms. The wave length of of such radiation is, however, much shorter than that of the visible light spectrum. Because of this short wave length and higher energy, this radiation has a high penetration power.

The inactivation of food spoilage microorganisms is brought about by changes in the DNA molecules in the living cells. Because of its size and other properties, the DNA molecule is far more sensitive to radiation than the molecules of the food undergoing processing. As a result, bacteria, molds, and yeasts are killed long before any undue changes can take place in the flavor of the food itself. In contrast to heat processing, the product does not change, because its temperature is not raised significantly and no cooking occurs. This can be a major advantage where heat-sensitive products are involved.

3.2. Techniques:

There are two possible methods of irradiation; irradiation by electron beam, and gamma irradiation.

3.2.1. Electron beam irradiation:

Electron beam irradiation is accomplished in a device called an accelerator. A typical accelerator consists of an evacuated tube to the ends of which an electric potential difference is applied. At one end there is an ion source injecting charged particles into the tube. These arrive at the other end with higher energy. They then impinge on the target, the food and their energy is transferred to it as it passes by on a conveyor. Electron beams generate high energy electrons or beta particles. Beta particles are characterized by high dose rates and low penetration capabilities. Since the penetration of the beam is low, it is used only where surface sterilization will suffice (Nielsen, 1987). It is used mainly in drying inks and curing adhesives in printing and converting industry (Yost, 1984).

3.2.2. Gamma Irradiation:

Most popular irradiation source for gamma is Cobalt-60, though Cesium-137 is also effective; Cobalt is preferred over Cesium for several reasons: Cesium-137 is produced from the nuclear waste of the nuclear reactors, transporting this to a radiation center is a dangerous task (Garland, 1987). Cesium-137 remains dangerous for 600 years, so any leakage into ground water or atmosphere would be extremely dangerous (Moynihan, 1987). And also when disintegration or atomic decay Cesium gives out only one gamma ray, where as Cobalt gives out two gamma rays and hence it would take almost four times of Cesium than Cobalt to accomplish the same amount of processing (Yost, 1984).

Cobalt-59 is placed in a nuclear reactor and bombarded with neutrons and harmless Cobalt-59 is turned Cobalt-60, a highly radioactive isotope. Cobalt-60 emits only gamma rays, they are like X-rays but more powerful (Meyer, 1981). This has a half-life of 5.3 years, so it usefulness is limited, but the used material would at least be less radioactive when it finally did become a waste, which makes it easier to transport and dispose (Food irradiation, 1984) . It also has the advantages over other radio isotopes of not forming any gaseous decay products.

The food products in pouches, packages, crates or totes is carried along a conveyor belt through shielded radiation chamber with six-foot concrete walls. Once the chamber is sealed dozens of 18 inch long and 1/2 inch thick stainless-steel tubes filled with cobalt-60 are raised in a vertical position by 'source rack'-a metal rack, that is usually 8 feet high and 10 feet wide from a 20 foot deep pool of water (Yost, 1984). A characteristics blue glow in the water is produced by gamma rays.

Figure. 1 shows a schematic drawing of a typical irradiation plant. And Figure. 2 shows one of the irradiation plant actually in use in the U. S.

The rays go everywhere and they can not be turned off, so the irradiation plant runs seven days a week. The rays are taken out of service by lowering the source rack into a water filled storage tank. And, to begin irradiating the rack is simply raised into position.

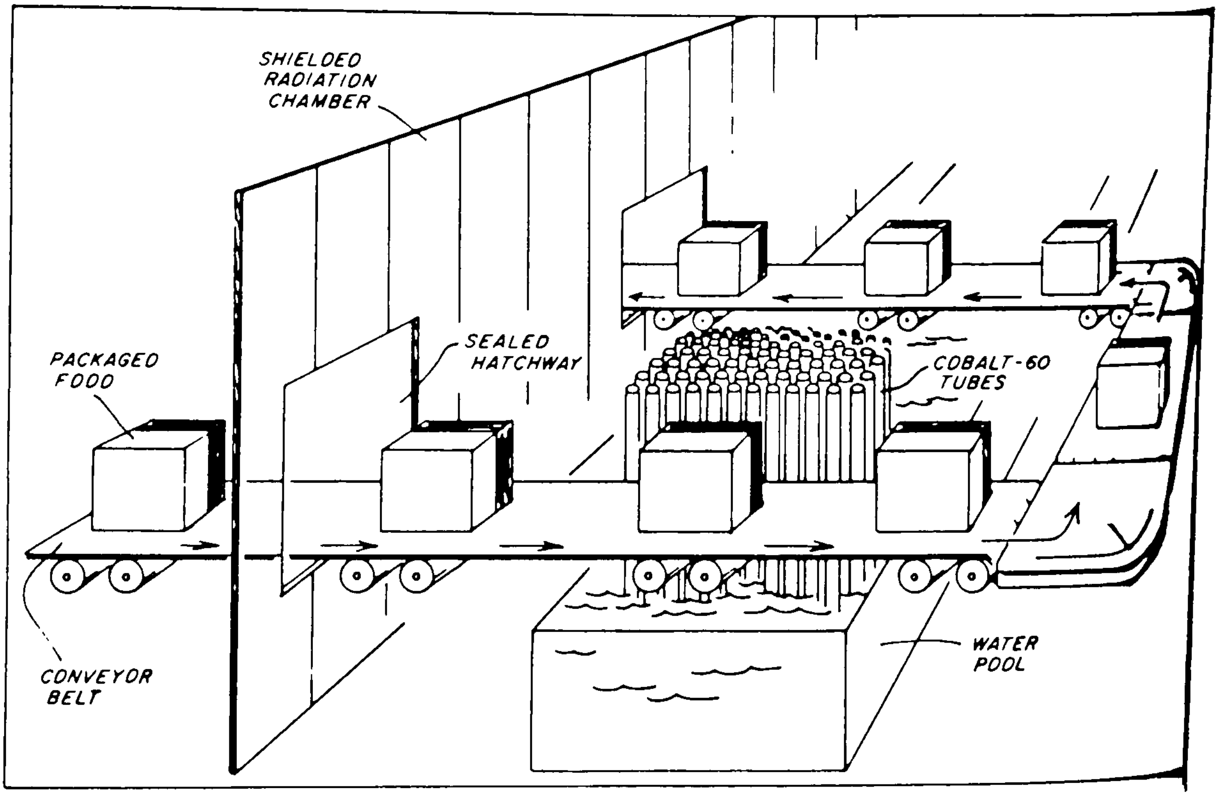

Figure. 1. Schematic drawing of a typical irradiating plant

Source: IEEE Spectrum, 1984

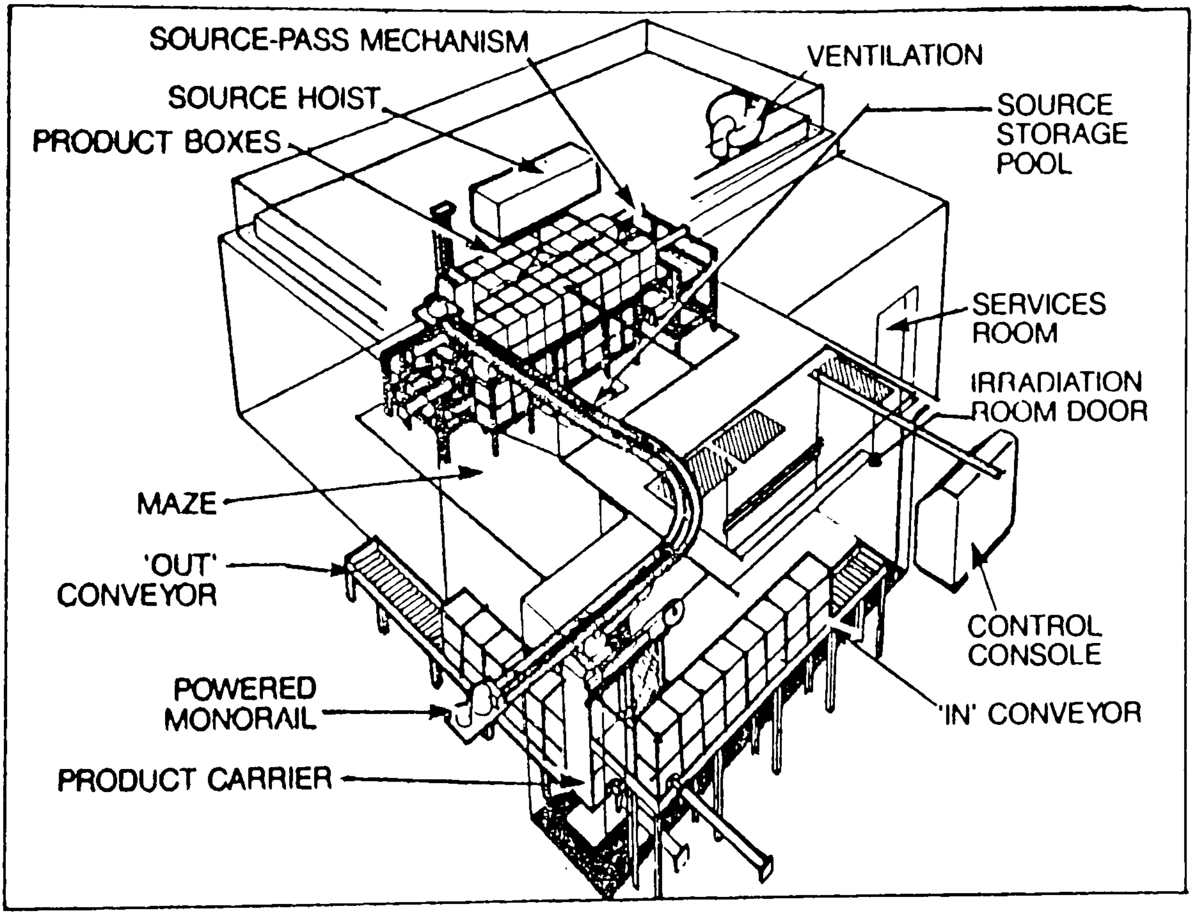

Figure. 2. Irradiation plant in use in the U.S

Source: Field Report, Food Engineering, 1984

4. WVTR TEST METHODOLOGY

One of the important stages of development of packages for irradiation is to test the materials and evaluate performance to confirm the suitability of selected materials for irradiated food products.

This study examines whether irradiated packaging materials undergo any changes in their barrier properties, particularly water vapor permeation, at currently accepted levels of radiation.

Ten commercially available barrier materials used for this study are: polyethylene terephthalate copolymer (PETG), polyethylene terephthalate coextruded with polyethylene (PET/PE), polypropylene (PP), oriented polypropylene (OPP), polyethylene(PE), polyethylene terephthalate (PET), Nylon coextruded with Polyethylene, Polystyrene, Medical Grade Paper, and Tyvek.

The packaging materials are irradiated at four dosage levels, namely 2.5Mrads, 5.0Mrads, 7.5Mrads, 10.0Mrads. The materials are divided into five groups. The first one being the non irradiated group or the control group.

One method of determining the rate of vapor permeability of a material is by using an infrared detection technique.(ASTM F 372-73 reapproved in 1984).

This method covers a rapid procedure for determining the rate of water vapor transmission of flexible barrier materials in film or sheet form. The apparatus used for this study is manufactured by Modern Controls Inc.

The flexible barrier materials were shipped to Radiation Sterilizers Inc. to be radiated at the Schaumburg plant in four corrugated cartons for four different levels of radiation dosages. Rates of water vapor transmission of different materials were determined approximately 10 weeks after they were irradiated.

Seven commercially available food packaging materials and three medical products packaging materials were selected for this study. The average results from each material's water vapor transmission rate will be used for the record. The data collected from 15 samples will be used to plot the graphs to see the effect of radiation on the material's vapor transmission rates at different levels of the radiation dosages. And the data obtained from the infrared detection technique would be statistically analyzed. The main objective of the statistical analysis is to establish relationships which make it possible to predict one or more variables in terms of others. In this study the relationship between the rate of water vapor transmission and the radiation dosage is established to confirm the effect of radiation on packaging materials. The null hypothesis is that irradiation has no effect on the rate of water vapor transmission of the ten packaging materials.

The statistical analysis consists of one way variance analysis to either accept or reject the null hypothesis. Null hypothesis is used for any hypothesis set up primarily to see whether it can be rejected, and the idea of setting up a null hypothesis is to precisely confirm beyond any reasonable doubt, the assumption could be accepted or not (Freund, 1979). And to confirm that there is change in the rate of water vapor transmission after radiation, and regression analysis of data to relate the rate of water vapor transmission to the radiation dosage with regression coefficient to further confirm the positive effect of radiation on the selected packaging materials.

5. Results and Discussion

The average of the data recorded from the Mocon Permatran/W (Table. 6) shows an significant change in the rate of water vapor transmission when observed at 95% confidence level. But when considered individually there seems to be a change and also when statistically analyzed, the rejection of null hypothesis, and to derive a relationship between the rate of water vapor transmission and the radiation dosage with a regression coefficient was possible.

To consider the problem of deciding whether observed differences among the sample means can be attributed to chance, or whether there are real differences among the means of the populations sampled, for instance, in this study the effectiveness of irradiation on the rate of water vapor transmission at different dosage levels is investigated. To confirm the effectiveness of irradiation on the rate of water vapor transmission of the ten commercially available packaging materials selected for this study, analysis of variance is used, so that , with reasonable assurance, statistically significant results can be attributed to particular causes, in this study it is irradiation dosage levels.

The variance ratio is the important factor in deciding whether null-hypothesis could be accepted or rejected at k-1 degrees of freedom for the numerator and k(n-1) degrees of freedom for the denominator if the comparison of means of k random samples of size n.

In this study for instance for PETG: where 15 random samples of 5 means are considered. Where k=5 and n=15, hence k-1=4, and k(n-1)=70.

The degrees of freedom in the numerator is 4 and degree of freedom in the denominator is 70 and hence the variance ratio at 0.05 level of significance is 140.28, which exceeds 2.503 the value of variance ratio at 0.05 level of significance. Statistically the results show a significant change in the rate of water vapor transmission at different dosage levels, hence the null-hypothesis is rejected with reasonable assurance and the significant change in results can be attributed to particular cause, in this case to irradiation. Similarly for all other nine packaging materials the value of variance ratio was determined, and the values were found be

exceeding the value of 2.503.

Regression analysis is to find a relationship between the rate of water vapor transmission and radiation dosage, in the case of PETG:

It shows a linear relationship between WVTR and radiation dosage.

WVTR = 1.43 + 0.0343 Radiation dosage.

Table. 6. Effects of Radiation on the Rate of Water Vapor Transmission of Packaging Materials Tested in this study (Grams/100in^2/24hrs @100°F, 90%R.H)

MATERIALS	0	2.5mrads	5.0mrads	7.5mrads	10.0mrads
PETG	1.42	1.52	1.57	1.76	1.73
PET/PE	0.46	0.48	0.50	0.55	0.57
PP	0.19	0.21	0.21	0.23	0.24
OPP	0.30	0.33	0.33	0.35	0.37
PE	0.12	0.13	0.15	0.15	0.13
PET	0.25	0.28	0.28	0.29	0.28
NYLON/PE	0.26	0.29	0.34	0.37	0.37
Polystyrene	0.98	1.01	1.27	1.27	1.27
MGP	5.62	5.92	5.92	5.91	5.92
TYVEK	5.69	5.91	5.91	5.91	5.91

[MGP: Medical Grade Paper]

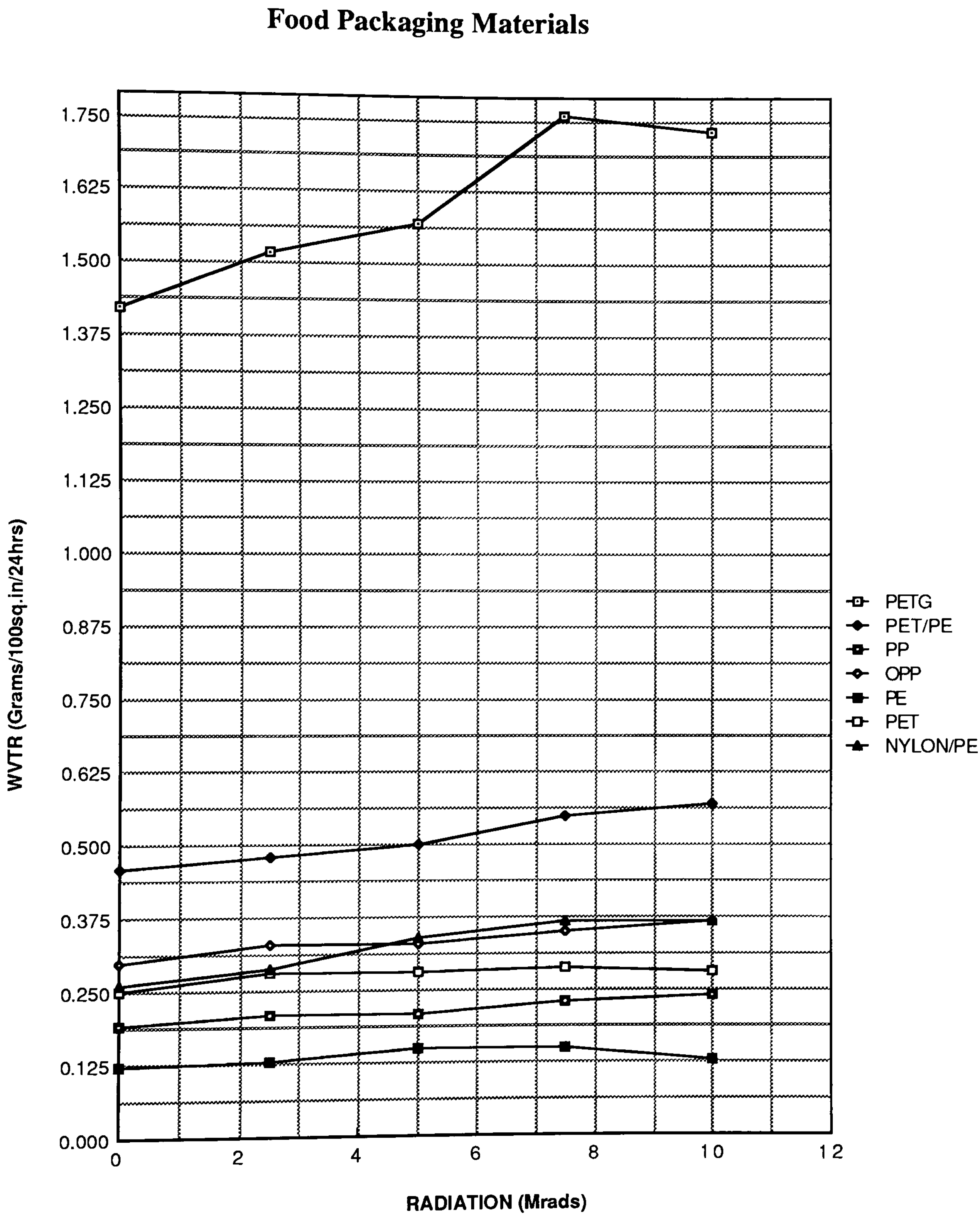

Figure. 3. WVTR Vs Dosage of Radiation of Food Packaging Materials

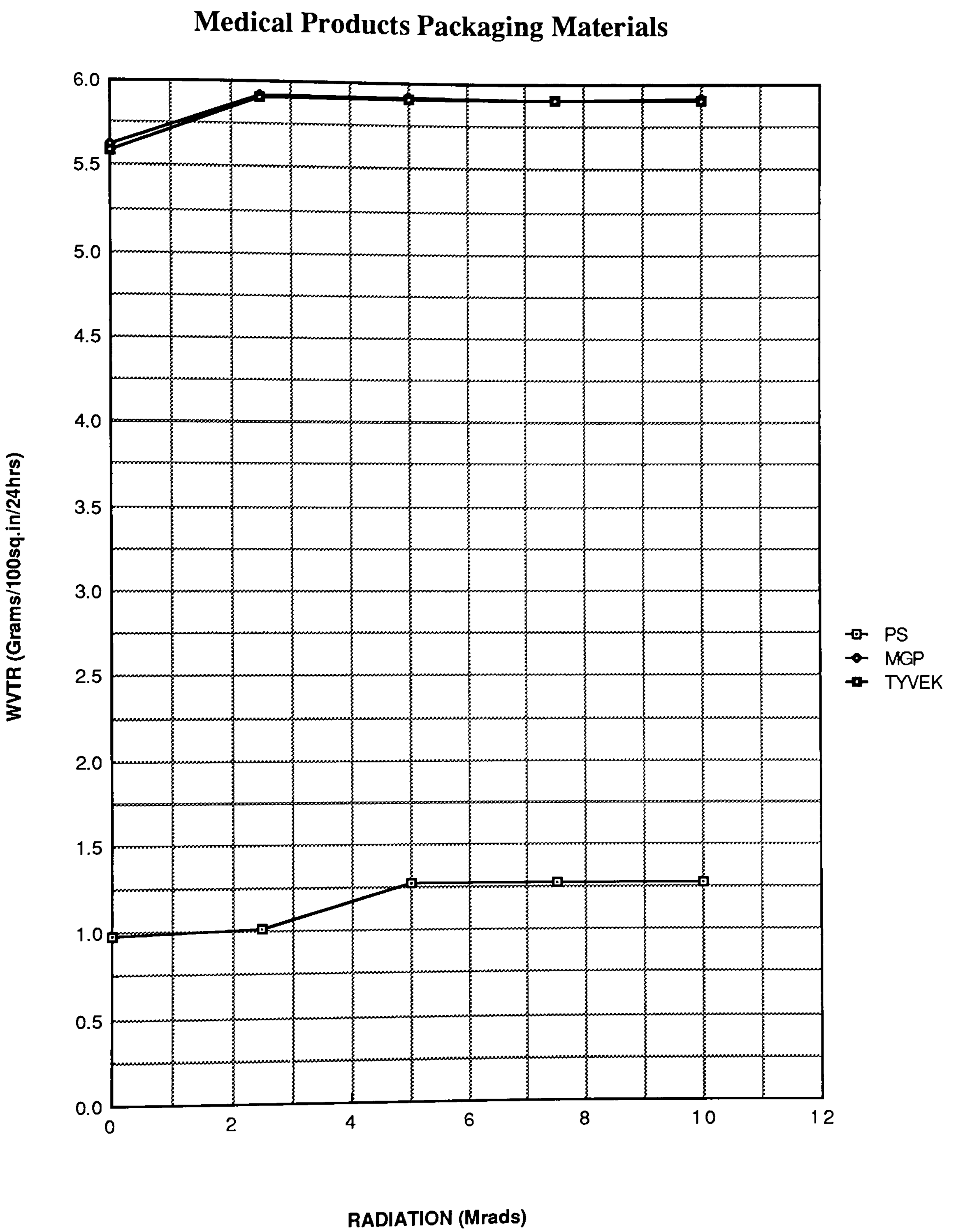

Figure. 4. WVTR Vs Dosage of Radiation of Medical Product Packaging Materials

Radiation increases the rate of water vapor transmission of Poly Ethylene Terphathalate Copolymer (PETG). This could be observed from the graph in Figure. 5.

One way analysis of variance shows the rejection of null hypothesis at 0.05 level of significance since F value 140.28 exceeds, 2.503 the value of $F_{0.05}$ for 4 and 70 degrees of freedom, regression analysis show the relationship between the rate of water vapor transmission and the radiation dosage as:

WVTR = 1.43 + 0.0343 Radiation Dosage - - - - - - - - Equation.1

WVTR: Water Vapor Transmission Rate(grams/100in^2/24hrs, @100°F,90%R.H)

Radiation Dosage: Dosage of Radiation (Megarads)

Which proves the effect of radiation on the rate of water vapor transmission of Poly Ethylene Terphathalate Copolymer

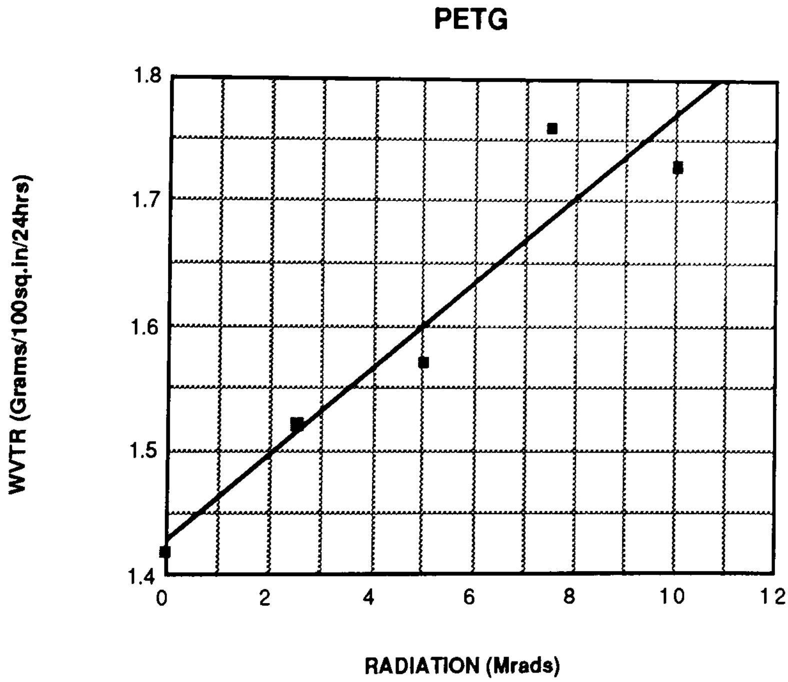

Figure. 5. Effects of irradiation on PETG

Radiation increases the rate of water vapor transmission of Poly Ethylene Terphathalate/Polyethylene. This could be observed from the graph in Figure. 6

One way analysis of variance shows the rejection of null hypothesis at 0.05 level of significance since F value 41.55 exceeds, 2.503 the value of $F_{0.05}$ for 4 and 70 degrees of freedom, regression analysis show the relationship between the rate of water vapor transmission and the radiation dosage as:

WVTR = 0.455 + 0.116 Radiation Dosage - - - - - - - - Equation. 2.

Which proves the effect of radiation on the rate water vapor transmission of Poly Ethylene Terphathalate/Polyethylene.

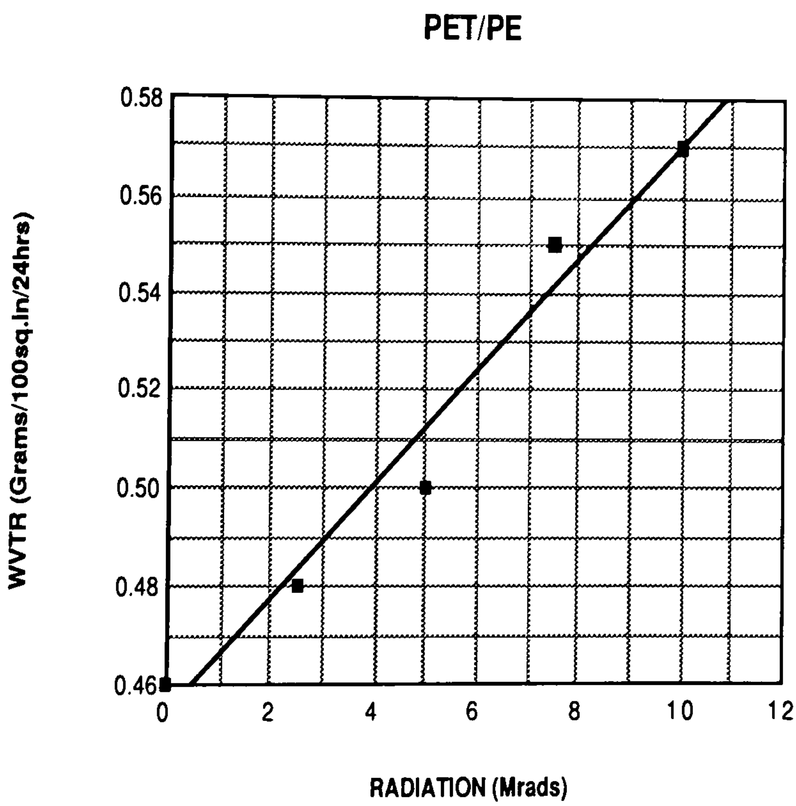

Figure. 6. Effects of irradiation on PET/PE

Radiation increases the rate of water vapor transmission of Polypropylene.This could observed from the graph in Figure. 7.

One way analysis of variance shows the rejection of null hypothesis at 0.05 level of significance since F value 8.14 exceeds, 2.503 the value of F0.05 for 4 and 70 degrees of freedom, regression analysis show the relationship between the rate of water vapor transmission and the radiation dosage as:

WVTR = 0.192 + 0.0048 Radiation Dosage - - - - - - - - Equation. 3.

Which proves the effect of radiation on the rate of water vapor transmission of Polypropylene.

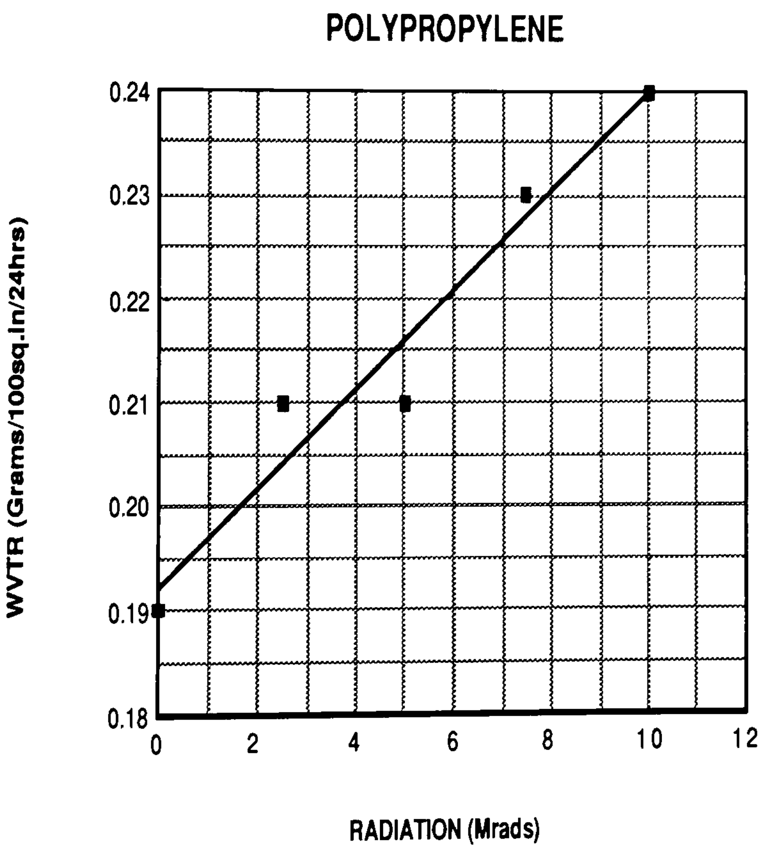

Figure. 7. Effects of irradiation on Polypropylene

Radiation increases the rate of water vapor transmission of Oriented Polypropylene. This could be observed from the graph in Figure. 8.

One way analysis of variance shows the rejection of null hypothesis at 0.05 level of significance since F value 12.59 exceeds, 2.503 the value of $F_{0.05}$ for 4 and 70 degrees of freedom, regression analysis show the relationship between the rate of water vapor transmission and the radiation dosage as:

WVTR = 0.304 + 0.00648 Radiation Dosage - - - - - - - - Equation. 4.

Which proves the effect of radiation on the rate water vapor transmission of Oriented Polypropylene.

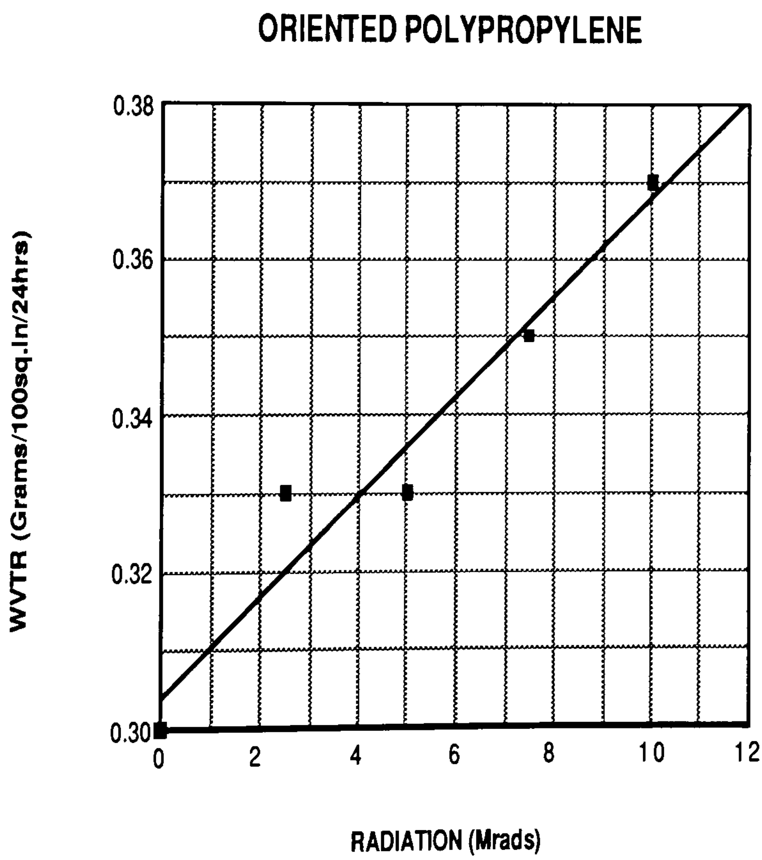

Figure. 8. Effects of irradiation on Oriented Polypropylene

Radiation increases the rate of water vapor transmission of Polyethylene.This could be observed from the graph in Figure. 9.

One way analysis of variance shows the rejection of null hypothesis at 0.05 level of significance since F value 3.82 exceeds, 2.503 the value of $F_{0.05}$ for 4 and 70 degrees of freedom, regression analysis show the relationship between the rate of water vapor transmission and the radiation dosage as:

WVTR = 0.128 + 0.00168 Radiation Dosage - - - - - - - - Equation. 5.

Which proves the effect of radiation on the rate water vapor transmission of Polyethylene.

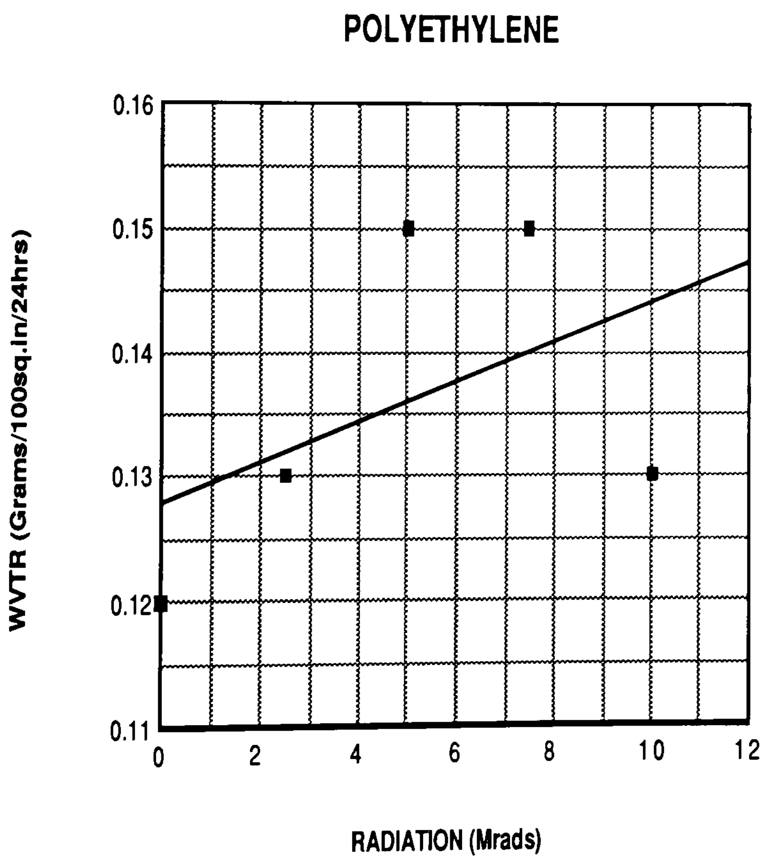

Figure. 9. Effects of irradiation on Polyethylene

Radiation increases the rate of water vapor transmission of Poly Ethylene Terphathalate. This could be observed from the graph in Figure. 10.

One way analysis of variance shows the rejection of null hypothesis at 0.05 level of significance since F value 2.52 exceeds, 2.503 the value of $F_{0.05}$ for 4 and 70 degrees of freedom, regression analysis show the relationship between the rate of water vapor transmission and the radiation dosage as:

WVTR = 0.263 + 0.0019 Radiation Dosage - - - - - - - - Equation. 6.

Which proves the effect of radiation on the rate of water vapor transmission of Poly Ethylene Terphathalate.

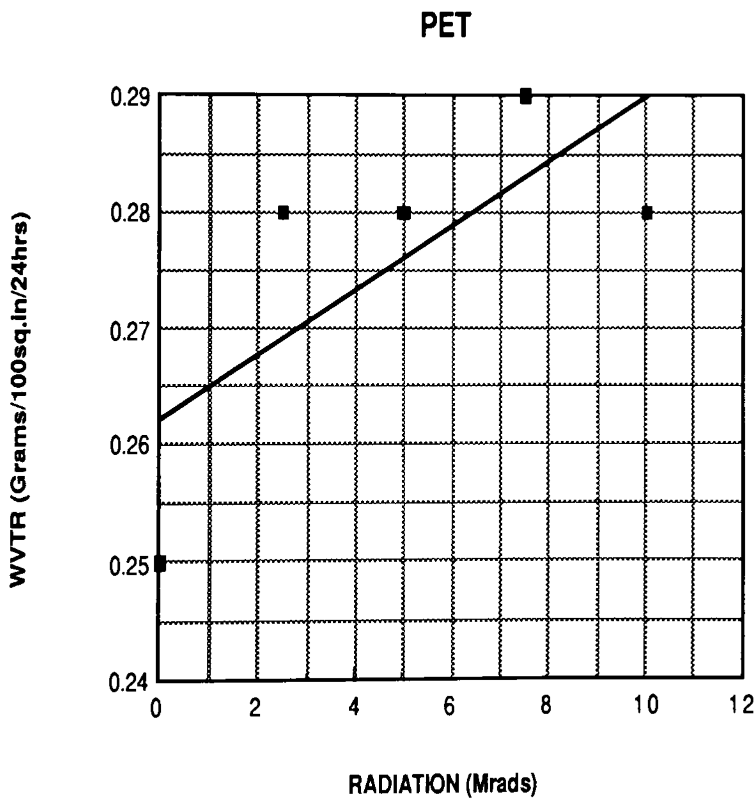

Figure. 10. Effects of irradiation on PET

Radiation increases the rate of water vapor transmission of Nylon/Polyethylene. This could be observed from the graph in Figure. 11.

One way analysis of variance shows the rejection of null hypothesis at 0.05 level of significance since F value 34.40 exceeds, 2.503 the value of $F_{0.05}$ for 4 and 70 degrees of freedom, regression analysis show the relationship between the rate of water vapor transmission and the radiation dosage as:

WVTR = 0.258 + 0.128 Radiation Dosage -------- Equation. 7.

Which proves the effect of radiation on the rate of water vapor transmission of Nylon/Polyethylene.

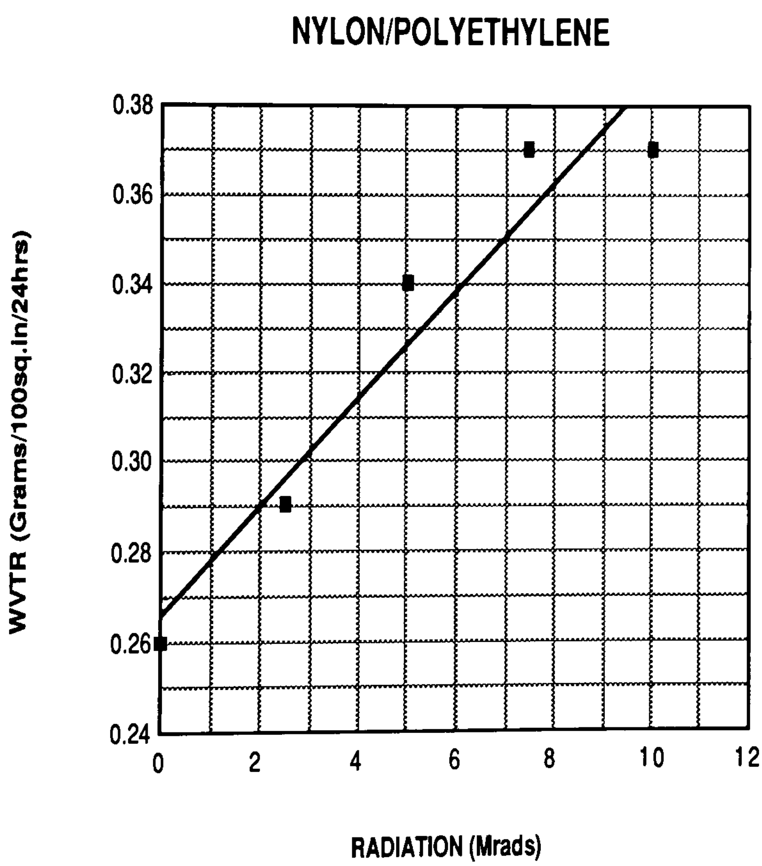

Figure. 11. Effects of irradiation on Nylon/PE

Radiation increases the rate of water vapor transmission of Polystyrene. This could be observed from the graph in Figure. 12.

One way analysis of variance shows the rejection of null hypothesis at 0.05 level of significance since F value 578.39 exceeds, 2.503 the value of $F_{0.05}$ for 4 and 70 degrees of freedom, regression analysis show the relationship between the rate of water vapor transmission and the radiation dosage as:

WVTR = 0.993 + 0.0335 Radiation Dosage - - - - - - - - Equation. 8.

Which proves the effect of radiation on the rate of water vapor transmission of Polystyrene.

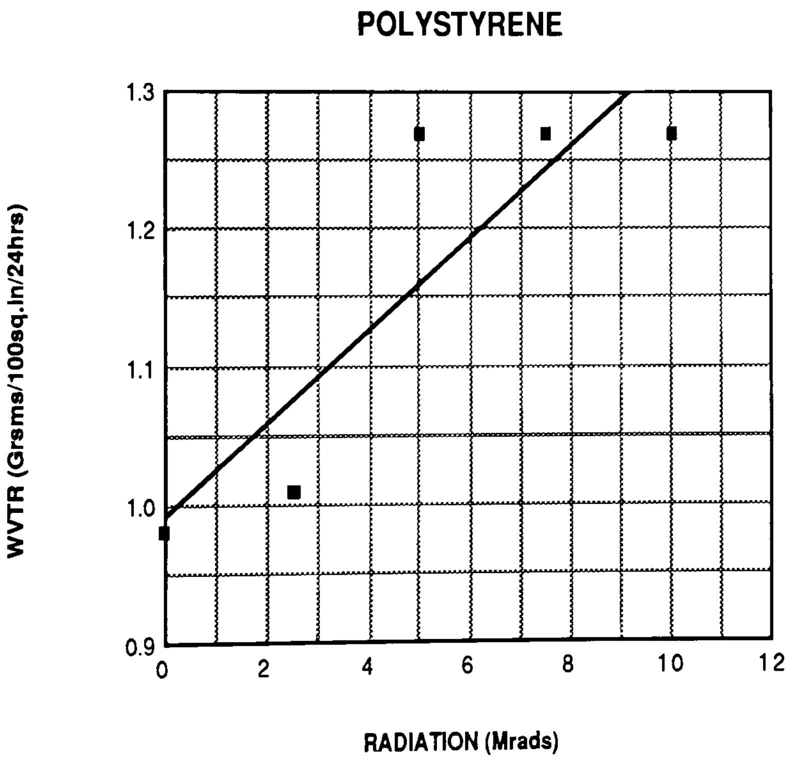

Figure. 12. Effects of irradiation on Polystyrene

Radiation increases the rate of water vapor transmission of Medical Grade Paper. This could be observed from the graph in Figure. 13.

One way analysis of variance shows the rejection of null hypothesis at 0.05 level of significance since F value 41.55 exceeds, 2.503 the value of $F_{0.05}$ for 4 and 70 degrees of freedom, regression analysis show the relationship between the rate of water vapor transmission and the radiation dosage as:

WVTR = 5.74 + 0.0236 Radiation Dosage - - - - - - - - Equation. 9.

Which proves the effect of radiation on the rate of water vapor transmission of Medical Grade Paper.

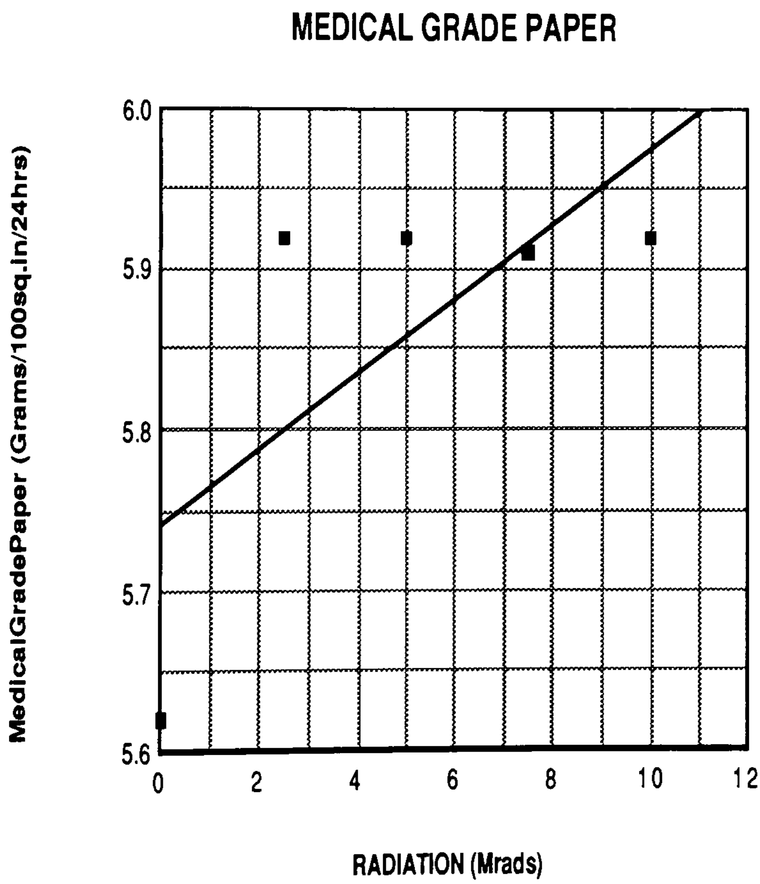

Figure. 13. Effects of irradiation on Medical Grade Paper

Radiation increases the rate of water vapor transmission of Tyvek. This could be observed from the graph in Figure. 14.

One way analysis of variance shows the rejection of null hypothesis at 0.05 level of significance since F value 303.78 exceeds, 2.503 the value of $F_{0.05}$ for 4 and 70 degrees of freedom, regression analysis show the relationship between the rate of water vapor transmission and the radiation dosage as:

WVTR = 5.77 + 0.0.194 Radiation Dosage ------- Equation. 10.

Which proves the effect of radiation on the rate of water vapor transmission of Tyvek.

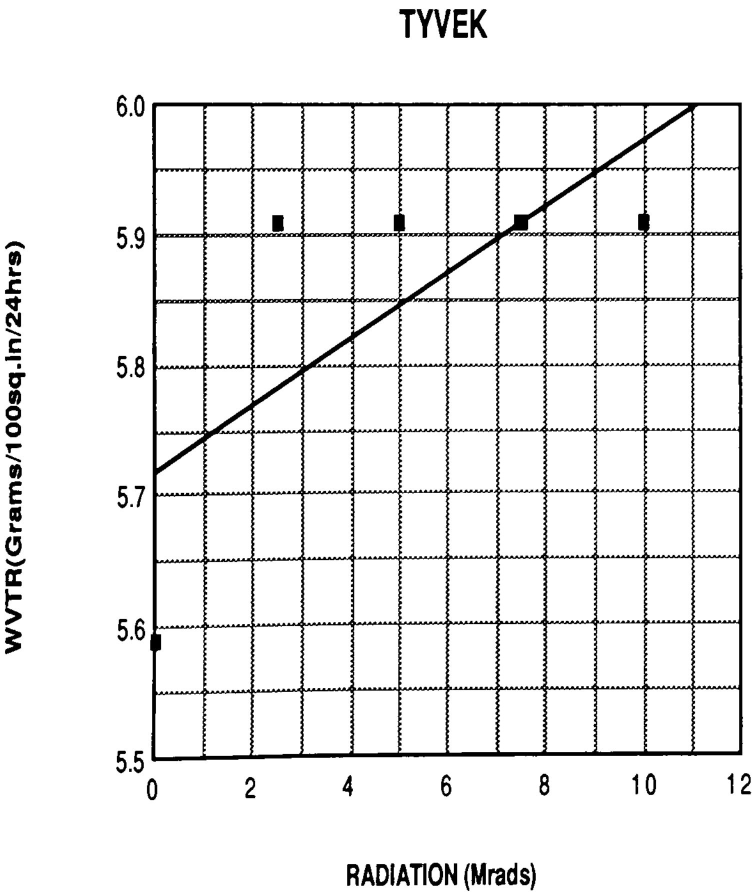

Figure. 14. Effects of irradiation on Tyvek

6. Conclusion and Recommendation

The rejection of null hypothesis and the subsequent findings of a relationship between the rate of water vapor transmission and the radiation dosage with a regression coefficient confirms the positive correlation of radiation on rate of water vapor transmission of the packaging materials.

The extension of shelf-life, reduction or elimination of pathogenic microorganisms, and spoilage organisms will not only make the consumer happy and healthier but also help the Governments to spend less on food related diseases.

Unlike the other preservation methods which have limited effects, or undesirable effects in protecting the product from microbiological attack and enzymatic degradation, irradiation emerges as an improved preservative method because of its efficiency in bacterial inhibition and subsequent improvement in the keeping qualities of the food products.

Extension of shelf-life and removal of both deterioration and poisoning will leave the food in as near a natural state as possible in appearance, texture, taste, and nutritional value allow the products to be distributed in a wide geographic area and would help solving the existing problems of starvation in the Third World countries. And also benefit the countries which are exporting the products overseas.

One of the advantages of the process is the fact that many food products can be treated after they have been packaged, this assists in keeping the food sterile until consumed.

The packaging materials should possess characteristics which ensures the food does not subsequently become recontaminated where irradiation is used as a preservation method to reduce the viable microorganisms in the food products. Hence the packaging materials used as containers for irradiated food products must be subjected to careful scrutiny to ensure their suitability and safety in use. Flexible packaging materials have special advantages and many plastic materials can be used for irradiated foods.

The study of the effects of irradiation on the existing packaging materials is important in developing packages for irradiated food products, hence further study including gas permeation testing are recommended to confirm the suitability of using the existing packaging materials for irradiated food products as a material of high gas permeation will adversely affect the preservation ability of the irradiation and will introduce microorganisms into the packages which will result in spoilage. It is important to identify the packaging materials which are capable of retaining the product without allowing any foreign items or particles being introduced.

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Appendix. A

Manufacturers and Specification of the Materials Tested

1. Polyethylene Terphthalate Copolymer (PETG)
   Eastman Chemical Products Inc.
   Gauge: 2.0 mil.

2. Polyester / Polyethylene
   Milprint Inc.
   Gauge: 3.0 mil.

3. Polypropylene
   Hercules Inc.
   Gauge: 5.0 mil.

4. Oriented Polypropylene
   Mobil Chemical Company.
   Gauge: 1.0 mil.

5. Polyethylene
   Gauge: 6.0 mil.

6. Polyester (Mylar)
   Du Pont de Nemours, E. I. & Co.
   Gauge: 7.0 mil.

7. Polyethylene / Nylon
   Sengwald.
   Gauge: 6.0 mil.

8. Polystyrene
   Penda Corporation
   Gauge: 9.0 mil.

9. Medical Grade Paper
   Tolas
   Gauge: 3.0 mil.

10. Tyvek
    Rollprint Packaging Products Inc.
    Gauge: 7.0 mil.

Appendix. B.

The Units of Radiation Processing

1 Rad	=	100 Ergs/Gram		
1 Gray	=	100 Rads		
	=	10^4 Ergs/Gram		
1 Kilorad	=	1000 Rads	=	10^5 Ergs/Gram
1 Kilogray	=	10^5 Rads	=	10^7 Ergs/Gram
	=	1 Joule/Gram		
	=	0.24 Calories/ Gram		
1 Megarad	=	10^6 Rads		
	=	10 KiloGray	=	1000 KiloRads
	=	10^8 Ergs/Gram		
	=	10 Joule/Gram		
	=	2.4 Calories/Gram		