24 Application Of Radiation In Bangladesh

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Abstract

Radiation technology offers a very wide scope for utilisation and commercial exploitation in various field. All over the world, this technology is being favourably considered for different applications like radiation sterilisation of medical products, preservation of food by controlling the physiological processes for extending shelf-life and eradication of microbial and insect pests, radiation processing of polymeric materials and treatment of sewage sludge.

Bangladesh Atomic Energy Commission has taken radiation processing programmes in a big way right from its inception. This paper describes the studies carried out by various research groups in Bangladesh Atomic Energy Commission mainly using Cobalt-60 gamma radiation. The investigation covers medical sterilisation, food preservation and development and modification of polymeric materials by gamma radiation. Both food preservation and radiation sterilisation of medical products are now being commercially carried out in the Gammatech facility as a joint venture company of BAEC and a private entrepreneur. Bangladesh is soon going to establish a full-fledged Tissue Bank to cater the needs of various tissue allografts for surgical replacement. Recently Government of Bangladesh has allocated US$ 1.00 million for strengthening of the Tissue Banking Laboratory. BAEC has made quite a good research contribution on vulcanization of natural rubber latex, wood plastic composites, surface coating curing, polymer modification etc. As a result of successful achievement of R & D activities in all these projects, a pilot plant project involving about US$ 4.00 million is under implementation at the Atomic energy Research Establishment campus of BAEC. In addition a project on 'National Polymer Centre' at a cost of US$ 2.00 million has already been approved. It is expected that work on radiation processing including commercialization will be accelerated with the implementation of these projects. The impact of radiation processing in selected areas will no doubt be significant in coming years.

Keywords: Radiation, applications, sterilization, processing, vulcanization, composites, hydrogel.

1. Introduction

Radiation technology namely the technology of utilization of intense radiation is a veritable source with immense potential for application in diverse fields. The knowledge about the effects of radiation on materials, components and systems opened up a new vista for large scale industrial exploitation. With the emergence of this new technology, the use of ionising radiation has to a very large extent revolutionised industrial scene all over the world during the last three decades.

The manifold advantages that radiation technology offers are of immense consequence to industry and potential benefits to public health and environment. The major applications of intense radiation include radiation sterilization of medical products, radiation preservations of food grains, radiation chemical processing, radiation polymerization, production of wood-plastic composites, radiation curing of paints and coatings and so forth.

It is worth while to indicate that the cost of conventional energy has multiplied manifold and is expected to go higher whereas the cost of radiation power has come down considerably. All over the world, there is a general tendency to re-evaluate the radiation route for industrial process techniques, so far discarded merely on the basis of poor economics.

With the availability of multi-kilo curie quantities of various radioisotopes as a consequence of the operation of nuclear power stations world-wide, utilization of this untapped potential of energy is of great technological significance to industry and public health in the country. Electron beam irradiation is fast catching up with gamma irradiation techniques in various parts of the world. Major breakthrough has been achieved in the areas of sterilization of sea foods, poultry products, cured coatings, cracking of cured petroleum and other allied fields.

Some of the major areas where research and development activities have been undertaken in this particular field in Bangladesh, and the current status of this programme with a glimpse into the future prospects are highlighted in this paper.

2. R & D activities at BAEC

During the last three decades, Bangladesh Atomic Energy Commission (BAEC) has undertaken an elaborate R & D programme covering a wide spectrum of activities in different fields of radiation processing research and its technological applications. This presentation is confined to the activities categorised as follows :

Radiation sterilization of medical products and pharmaceutical raw materials,
Radiation sterilization of tissue grafts for use in rehabilitative surgery,
Radiation preservation of foods,
Radiation biotechnology,
Radiation Vulcanization of Natural Rubber Latex,
Wood-plastic composites using gamma irradiation,
Curing of surface coatings by UV radiation, and
Preparation of hydrogel for burn dressing.

2.1. Radiation sterilization of medical products

Detailed investigations have been made on locally produced absorbent cotton, surgical bandages/dresings, family planing kits, empty ophthalmic bottles etc. in order to evaluate its bioburden and microbial radiosensitivity [1,2]. The contaminating bacteria and fungi have been isolated, purified, identified and the D_{10} value of some comparatively radioresistant isolates were determined. The cotton based products showed quite a high level of contamination sometimes showing values as high as 10^3 or 10^4 [1]. But now-a-days with stricter adherence to GMP the cotton based products have shown a remarkable increase in their microbiological quality. The radiation dose level for sterilization of different medical products ranged between 25 kGy to 30 kGy with a sterility assurance level (SAL) of 10^6 (Table 1).

2.2. Radiation sterilization of pharmaceutical raw materials

Extensive R & D was also carried out to explore possibilities of extending radiosterililization technique to sterilize certain pharmaceutical products which included antibiotics, steriods, vitamins etc. The following pharmaceutical raw materials were studied in detail to find their suitability for radiation sterilization.

Antibiotics : Oxytetracycline-HCl, Amoxicillin tri-hydrate, Chloramphenicol and Procaine penicillin G.

Steriods : Dexamethasone sodium phosphate.

Vitamins : Riboflavin 5'-phosphate and Thiamine HCl.

Each of the above mentioned raw materials were irradiated at doses of 5, 10, 25, 50 and 100 kGy and the consequent microbiological, physical and chemical changes were observed. In general, the products were examined for microbial load, colour, pH, potency, absorption spectra and HPLC to check if there was any degradation upon irradiation. Analytical studies failed to prove any physico-chemical, biological potency and safety alterations. It was evident from the above studies that all the samples tested are suitable for radiation sterilization even at a high dose of 50 to 100 kGy (Table 2 and3, Figure 1 and 2) [3,4]. Re-examination of radiosterilized antibiotics stored under room temperature for 12 months after radiation treatment showed compliance with BP requirements as regards physico-chemical and microbiological specifications.

Radiation sterilization is particularly well-suited for Bangladesh. The country lacks sterilization facilities in most areas. Regular supplies of radiation sterilized medical products can greatly improve the country's health care programmes. Bangladesh has made a modest beginning in this respect. Institute of Food and Radiation Biology of the Bangladesh Atomic Energy Commission offered radiation sterilization services to many governmental and autonomous organization and private companies since 1981. With the 50,000 Curie Co60 source , it became impossible to serve all the organizations and to meet the increasing demand of radiosterilized medical and pharmaceutical products.

The sterilization demand of the country was 68,000 cubic feet/year in 1985 which stood at 225,000 cubic feet/year in 1995 and it is increasing with the extension and improvement of the health care programmes. The country badly needs upgrading of the medical products, particularly those manufactured locally which will be sufficient for running a commercial irradiator year round. With these view in mind a commercial irradiator (100,000 Ci Co60) was installed at Chittagong, in 1993 under the joint venture of BAEC and BEXIMCO, known as GAMMATECH.

2.3. Tissue Banking

Tissue banking represents a well established service in many countries in the health sector where many different kinds of tissues are processed, sterilized and supplied. Tissue bank involves selection, collection, processing, storage and distribution of tissues for their subsequent clinical use. Skin, amnion membrane, bone, heart valve, tendon, dura mater, middle ear etc. are typical example of tissues that are converted to grafts. Radiation preservation has opened a new dimension in these areas. Properly processed grafts can now be effectively sterilized by radiation and preserved for long time without any loss of efficacy. In collaboration with the International Atomic Energy Agency (IAEA) a project on "Tissue Banking" was initiated at the Institute of Food and Radiation Biology (IFRB), Bangladesh Atomic Energy Commission at the end (December) of the year 1985.

Techniques for the preparation of radiation sterilized amnion membrane and bone grafts have been established. Fresh amniotic membranes and bones are collected from the labour unit of Azimpur Maternity Hospital, Gonoshastho health complex, from the operation theater of Dhaka Orthopaedic Hospital (RIHD) and Dhaka Medical College Hospital respectively. The prepared amnion membrane and bone allograft are sterilized by gamma irradiation (20/25 kGy)[5,6,7]. Radiation sterilized amnion and bone grafts are now being prepared and supplied regularly to 12 different hospitals of the country. Since the out-set of the research work on tissue banking in Bangladesh more than 13,500 amniom and bone allografts were prepared and 700 different types of patients (burn, leprotic ulcer, bedsore, traumatic open wound, diabetic wound, orthopaedic and maxillo-facial defective) were successfully treated with these radiation sterilized tissue allografts (Figure 3 and 4) [8].

The ultimate objective of the present research and development activities on Tissue Banking in Bangladesh is to establish a full-fledged TISSUE BANK to cater the needs of various tissue allografts for surgical replacement. Recently Government of Bangladesh has allocated 1.00 million US$ for strengthening of the Tissue Banking Laboratory.

2.4. Food Irradiation

Radiation provide effective means for preservation of foods by controlling the physiological processes that cause spoilage and through eradication of microbial and insect pests. Research and development work at BAEC has involved obtaining substantial basic information on spoilage factors - enzymatic, microbial and chemical - along with evaluation of nutritional and organoleptic quality aspects and toxicological safety of irradiated foods. This approach was necessary since the main objective has been on the extension of post-harvest storage of various items in natural form.

The studies carried out at BAEC have been aimed at the following applications :

(i) Disinfestation of pulses
(ii) Sprout inhibition in potatoes and onions
(iii) Delayed ripening of fruits
(iv) Extension of shelf life of fish and meat
(v) Elimination of food borne pathogens
(vi) Microbial decontamination of pathogens
(vii) Promotion and commercialization of food irradiation technology

Research has been carried out on preservation and shelflife extension of a number of food items such as potato, onion, sweet potato, dried fish, fish, poultry, fruits and vegetables[9,10,11,12,13]. Pilot and semi-commercial scale irradiation and storage studies of promising food items such as potato, onion, dried fish and pulses were carried out in collaboration with the wholesalers and traders (Table 4). Process parameters for irradiating different food items were established (Good Irradiation Practice). Nutritional and toxicological studies have been conducted on irradiated food items. Consumer acceptability trials and test marketing of irradiated products were carried out. It has been found from the test marketing studies that the consumers have accepted irradiated products very favourably, especially when the superior quality and hygiene of the irradiated products are immediately apparent [14].

To provide the legal framework for the commercialization of the food irradiation technology, clearance for irradiation of 13 food items was issued by the Bangladesh Government in 1983 (Table 5).

Based on these developments a demonstration-cum-commercial Cobalt-60 irradiation plant was set up in March 1993 in the port city of Chittagong as a joint venture project (GAMMATECH Limited) of Bangladesh Atomic Energy Commission and Beximco- a leading private company in the country. By May 1997, GAMMATECH Ltd. irradiated 909,943 kg of different food items brought by clients and these items have been marketed successfully both at home and abroad (Table 6). Every year new items are being added to the list of food items being irradiated and marketed (Table 7). GAMMATECH now earns about Tk. 22,00,000 to Tk. 24,00,000 annually as service charge for irradiation and can meet about 95 - 100% of its operational expenses.

Later on, for harmonization of regulation, Bangladesh adopted in 1995 a 'Specification for Authorization of Irradiation by Groups/Classes of Foods' in line with the guidelines framed by ICGFI which has been formed under the aegis of IAEA, FAO and WHO. This will replace the clearance given earlier to irradiation of individual food items.

2.5. Sterile Insect Technique

Large scale laboratory rearing and radiosensitivity of some economically important pests such as, blow flies, fruit flies (e.g. melon fly and oriental fruit fly), jute hairy caterpillar have already been established as a prerequisite for the eradication / suppression of the concerned pests through SIT. A preliminary survey and trapping of blow fly for species identification and density of target pest have been conducted in the off shore island Sonadia[15].

2.6. Biotechnology

Biotechnology work in this field may be broadly classified under two broad heading, (i) upgrading of agro-wastes by radiation and fermentation processing. (ii) development of useful mutants through low dose of gamma irradiation.

Currently work on the following programmes are being conducted at BAEC:

(a) Isolation of good fungal and bacterial strains and to develop good enzyme system for obtaining fermentable sugars from residues like sugarcane, bagasse, jute stick, rice straw, saw dust etc[16, 17, 18].

(b) Effects of radiation and other physical and chemical methods on enzymatic digestion of lignocellulosic wastes[19].

(c) Bioconversion of cellulosic and other residues to different useful products through saccharification and fermentation.

(d) Development of useful mutants through low dose of gamma irradiation of certain microorganisms for citric acid fermentation[20, 21].

2.7. Radiation Vulcanized Natural Rubber Latex

Bangladesh produces about 15,000 metric tons natural rubber field latex. In 1990 the project was taken under the financial assistance of IAEA. Laboratory scale production of concentrated latex production was started with help of the separator machine obtained from IAEA. Two experts from Japan (Dr. K. Makuuchi and Dr. F. Yoshii of JAERI) and one expert from Indonesia Dr. Marga Utama helped to start the project. The characteristic properties of the latex concentrate thus obtained were evaluated and compared to those as required by the ISO. Bangladeshi latexes posses very good quality. The process of vulcanization of natural rubber latex by radiation and sesitizer(chemical used to reduce the vulcanization dose) has been optimized and the optimum radiation dose is around 12 kGy [22-26] shown in figures 5-6. Rubber products like hand gloves, baby teats, balloons, etc. have been prepared with radiation vulcanized latex and these posses good qualities. The storage stability of rubber films has been observed in open air in the laboratory and found that the properties remain good for a long period shown in figures 7-8. By coating the radiation vulcanized latexes on jute mats/ hessian cloths, jute-rubber combination has been prepared and this is expected to enhance the field of application of jute in the market of home and abroad. Some individual small companies have shown interest to adopt the technology. Bangladesh does not produce concentrated latex, so individual manufacturers of dipped products import latex concentrate from abroad. Some private rubber gardens are interested to procure industrial scale separator.

2.8. Hydrogel for medical Application

The polymer based hydrogel material would be prepared using various monomers/polymers and additives by radiation technique for treatment of patients with burn injuries. IAEA would provide financial/technical support to implement the project through BGD/2001/005PL for 2001-2002. Experts from IAEA (Dr. Yoshii F., Japan; Dr. Rosiac J., Poland; Dr. Guven O., IAEA) would help to initiate the project. After completion of the project the product would be produced on large scale in the Pilot Plant

2.9. Surface Coating Curing

A formulated solution is coated on a substrate (wood, leather, hessian cloths etc) and then cured by radiation to make film on the surface of the substrate, selection of coating formulation depends on the nature of the substrate on which coating is made. Flexible coated film is made on the flexible surface like leather hessian cloths, etc. and is prepared with urethane type oligomer in combination with other monomers and additives. Similarly hard coating is obtained using formulation polyester oligomer for the surface of hard substrate like wood and wood products.[27]. Figure 9 shows the properties of cured wood surface containing various percentage of additives (sand in base coat). Bangladesh exports leather worth about Tk. 500 crore each year. Tanning on the raw leather essential to improve properties of raw leather and it is quite expensive. Coating on raw leather improves surface properties and reduces the coating of tanning. The strength of the coated leather is slightly improved and the treated leather can be stretched by 75% more than the untreated leather. Modification of natural rubber, wood, silk by radiation to yield better quality products.

2.10. Wood Plastic Composite

Wood is a versatile engineering material used in almost every sphere of life starting as propeller shaft in nuclear submarine to kitchen as spoon. The use of wood is increased with the growth of industrialization. But production of wood depleting very fast with modernization and high quality wood has almost disappeared while low quality wood faces qualitative problems. WPC project was taken under the financial assistance of IAEA. Low quality woods (simul, korai, kadam, mango, debdaru etc.) after impregnation with monomers (MMA, AN, etc.) and additives (urea salts etc.) are exposed to gamma radiation to prepare wood plastic composites. The wood composite thus prepared has acquired enhanced mechanical strength by more than 90% decreased moisture/water absorption by 50% and its resistance to chemical salt corrosion and attacks by insets microbes etc. It has very low abrasion (wear and adhesion) loss [28-32]. Figure 10 shows the results of WPC prepared by impregnating with monomer MMA containing urea as additive.

2.11. Jute Rubber, Jute Plastic Composites

Jute is a type of natural fiber which grows abundantly in Bangladesh. With the advent of synthetic fibers, use of jute has enormously depleted. With a view to improve properties like, strength, water resistance etc. BAEC has taken works to coat hessian cloths as well as to graft jute fibers/string/treads with RVNRL or monomers and additives. Rubberized jute material has improved water resistance and very good as a packaging material. Polymer coated jute material is durable in dry soil and water but quite degradable in mud and soft day.

2.12. National Polymer Composite Centre

The objective of the project is to achieve design and development of durable and sustainable polymer composites reinforced with polymer resins and indigenous natural fiber and synthetic fibers of glass and carbon origins which can be used to fabricate unbreakable civil structural materials such as sewerage pipes, water pipes, parts of electronic appliances, cables, door and window frames, staircases, tables etc. The project has been approved by the Government of Bangladesh and the cost of the project is approximately US$ 2 million.

3. Regulatory aspect

Bangladesh promulgated in 1993 a "Nuclear Safety and Radiation Control" Act covering all activities related to nuclear sources and devices and use of radioactive materials. Subsequently NSRC rules were gazetted in 1997. Establishment and operations of all radiation processing facilities are governed by the provisions of the National Nuclear Safety and Radiation Control Rules.

4. Conclusion

The application of gamma irradiation for radiation sterilisation of medical products and food irradiation has been fully demonstrated in the country. The areas of production of wood-plastic composites, RVNRL and curing of surface coating are in the process of exploitation on a semi-commercial scale.

Electron beam irradiation techniques for other applications like radiation curing of paints, wire and cable insulation, production of heat shrinkable plastics, vulcanisation of rubber open up new areas which need to be set up and demonstrated in the country.

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Table 1: Estimated sterilisation dose for absorbent cotton wool and surgical gauze and a single recommended dose for cotton based medical products.

Medical Products	Radiation resistant isolate	Maximum initial microbial count (CFU/g)	D_{10} values of the isolates (Mrad)	Estimated safety level sterilisation dose (Mrad)
Absorbent cotton wool	ACR-OR	3.3×10^2	0.213	1.70
	ACR-LU	4.1×10^3	0.298	2.68
	ACR-MI	3.5×10^3	0.220	1.98
	ACR-ME	2.8×10^2	0.215	1.93
	ACR-MU	1.1×10^2	0.187	1.50
	ACR-PE	1.9×10^3	0.201	1.81
Surgical Gauze	SGR-OR	5.1×10^2	0.246	1.97
	SGR-LU	4.9×10^3	0.180	1.62
	SGR-MI	3.7×10^3	0.240	2.16
	SGR-ME	3.4×10^2	0.270	2.16
	SGR-MU	4.6×10^3	0.158	2.42
	SGR-PR	5.9×10^3	0.294	2.42
Recommended*		5.9×10^3	0.298	2.911

*One single dose recommended for cotton based medical products (absorbent cotton wool and surgical gauze), based on maximum contamination level (5.9×10^3 CFU/g) and the highest radioresistance (D_{10} value 0.298 Mrad) of the isolate.

Sterilisation Dose (S.D) recommended = $0.298\,(\text{Log } 5.9\times10^3 - \text{Log } 10^{-6}) = 2.911$ Mrad

Table 2: Determination of biopotency of control and irradiated oxytetracycline HCl powder as done by disk diffusion and turbidimetric method.

Radiation dose (kGy)	Diameter of zone of inhibition (mm) by disk diffusion method (Kirby-Bauer)	Potency (mg/g) turbidimetric method
Control (unirradiated)	8.30	912.00
10	8.25	916.76
25	8.20	921.36
50	8.15	924.74
100	8.30	900.65

Table 3: HPLC retention time and area of control and irradiated samples of Oxytetracycline HCl powder

Radiation dose (kGy)	Retention time (minute)	Area
Control (unirradiated)	15.30	2,06,369
10	15.33	1,95,986
25	15.37	1,98,481
50	15.38	2,02,304
100	15.40	2,02,153

Table 4: Test marketing of irradiated potatoes, onions and dried fish in 1984 – 1988 seasons.

Months	Sales in kg in different seasons			
	1984	1985	1986	1988
Irradiated potatoes				
August	1000	1000	1200	500
September	1600	1500	2000	2000
October	2500	3000	2500	4000
November	1100	800	800	-
Total	6200	6300	6500	6500
Irradiated onions				
September	1000	500	1500	300
October	1800	2000	5500	1000
November	2000	2000	4000	3000
December	700	500	2000	3000
January	500	500	1000	1000
Total	6000	5500	1400	8300
Irradiated dried fish				
July	250	250	500	500
August	250	250	500	500
September	250	250	500	500
October	250	250	500	500
Total	1000	1000	2000	2000

Table 5: Clearance for irradiation of 13 food items by the Bangladesh Government in 1983.

ITEM NAME	CODE & TYPE OF CLEARANCE		DATE	DOSE MAX (kGY)
CHICKEN	3	UNCONDITIONAL	83/12/29	7
CONDIMENTS	2	UNCONDITIONAL	83/12/29	1
CONDIMENTS	3	UNCONDITIONAL	83/12/29	10
FISH	3	UNCONDITIONAL	83/12/29	2.2
FISH (DRIED)	2	UNCONDITIONAL	83/12/29	1
FISH PRODUCTS	3	UNCONDITIONAL	83/12/29	2.2
FROG LEGS	3,5	CONDITIONAL	83/12/29	7
MANGO	1,2	UNCONDITIONAL	83/12/29	1
ONIONS	6	UNCONDITIONAL	83/12/29	0.15
PAPAYA	1,2	UNCONDITIONAL	83/12/29	1
POTATO	6	UNCONDITIONAL	83/12/29	0.15
PULSES	2	UNCONDITIONAL	83/12/29	1
RICE	2	UNCONDITIONAL	83/12/29	1
SHRIMP	3,5	CONDITIONAL	83/12/29	5
SPICES	2	UNCONDITIONAL	83/12/29	1
SPICES	3	UNCONDITIONAL	83/12/29	10
WHEAT	2	UNCONDITIONAL	83/12/29	1
WHEAT PRODUCTS	2	UNCONDITIONAL	83/12/29	1

Explanation for codes: 1. Delay ripening/physiological growth, 2. Disinfestation, 3. Microbial control, 5. Shelf-life extension, 6. Spouting inhibition.

Table 6: Item wise quantity of products irradiated and revenue earned by Gammatech Ltd.

Year / Products	1993 (July-Dec)	1994 (Jan-Dec)	1995 (Jan-Dec)	1996 (Jan-Dec)	1997 (Jan-May)	Total
Food items						
Dried fish (Kg)		129,959	494	154	1,815	132,422 Kg
Frozen foods (Kg)		8,842	319,453	276,193	58,642	663,130 Kg
Beef casing (Kg)		8,842	8,980	10,475	---	28,297 Kg
Bean/pulses (Kg)		---	2,000	---	4,000	6,000 Kg
Flour (Kg)		---	11,940	4,620	---	16,560 Kg
Turtle meat (Kg)		---	---	200	---	200 Kg
Macaroni (Kg)		---	---	33,176	30,158	63,334 Kg
Total (Kg)		**147,643**	**342,867**	**323,818**	**94,615**	**909,943 Kg**
Medical sterilisation						
Shell dressing (pcs)	9,542	---	10,260	---	---	19,802 Pcs
plastic bottle, caps, droppers etc (cft)	886	1,559	1,253	1,992	272	5,962 cft
Magnesium trisilicate (Kg)	7,650	---	5,120	---	---	12,770 Kg
Magnesium Silicate (Kg)	---	---	52,850	51,326	40,065	144,241 Kg
Revenue earned (Tk)	**379,504**	**812,930**	**2,400,000**	**2,300,000**	**680,000**	**6,572,434**

Table 7: Charges for Irradiation (The present charges for irradiating different items by Gammatech are as follows)

1. Potato and onion:	Tk. 0.50/kg	(1.25 US Cent/kg)
2. Dry fish and pulses:	Tk. 3.00/kg	(7.50 US Cent/kg)
3. Frozen fish and shrimp:	Tk. 5.00/kg	(12.50 US Cent/kg)
4. Medical products:	Tk. 250.00/cft	(6.25 US $/cft)

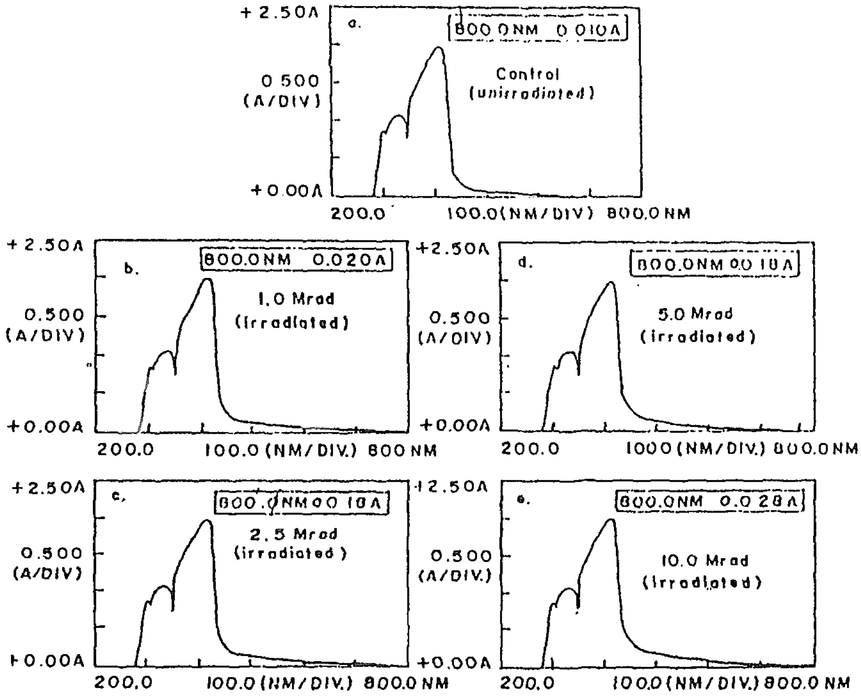


Figure 1. Absorption spectra of control and irradiated oxytetracycline-HCl powder

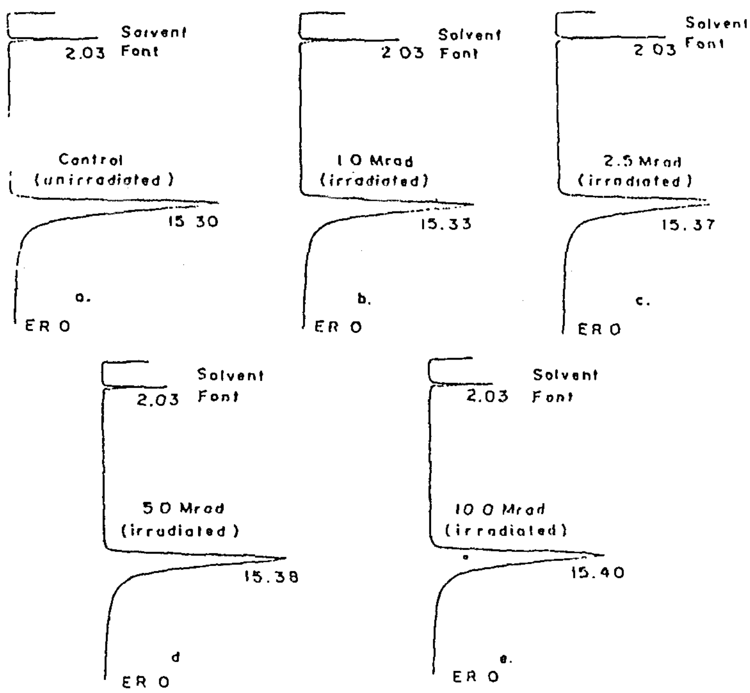


Figure 2. HPLC chromatogram of control and irradiated oxytetracycline-HCl powder

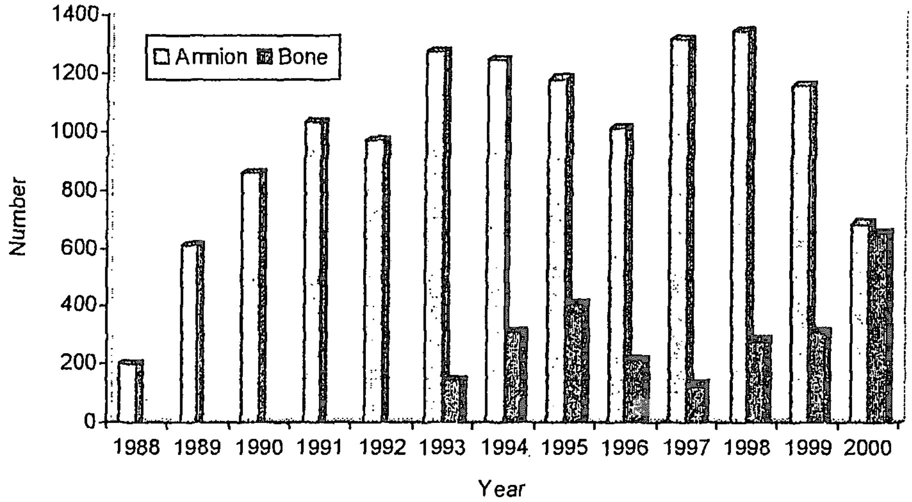


Figure 3 : Bar diagram showing the number of grafts prepeared and sterilization (1988-Sept. 2000).

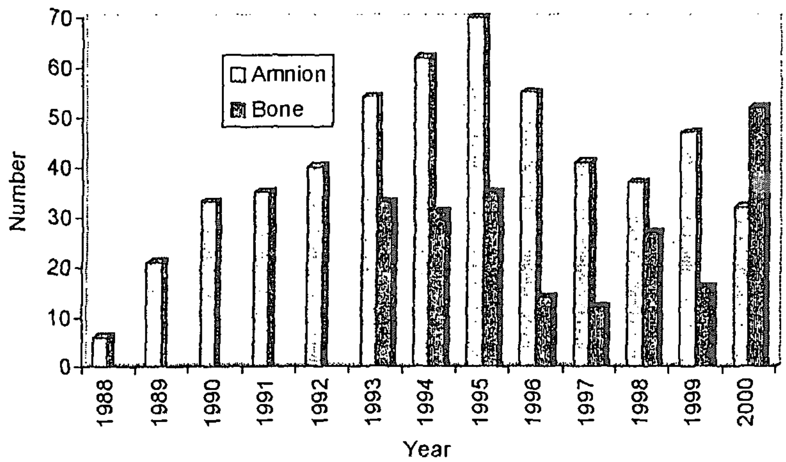


Figure 4 : Bar diagram showing the number of patient treated with radiation sterilized tissue allografts (Amnion & Bone)

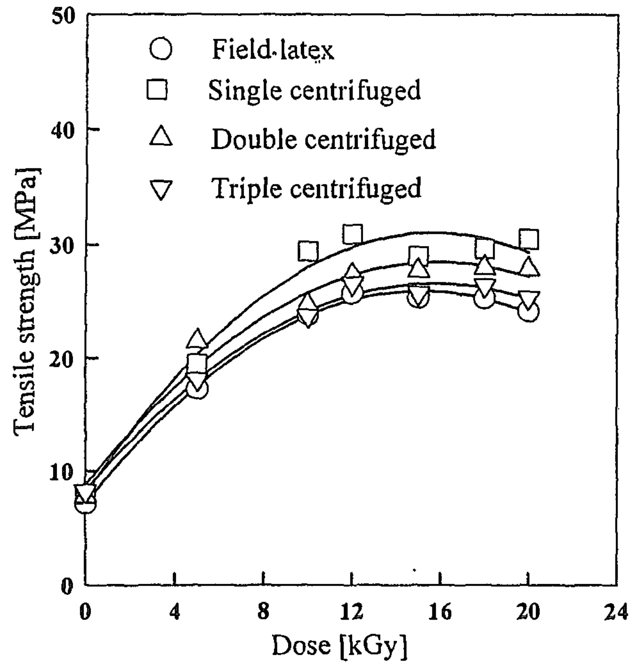


Fig. 5 Tensile strength of RVNRL film at various radiation doses.

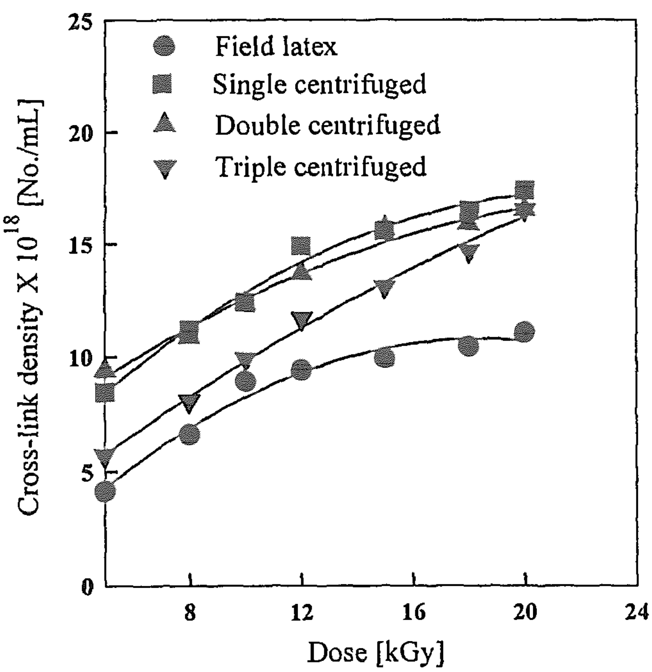


Fig. 6 Cross-link density of RVNRL film at various radiation doses.

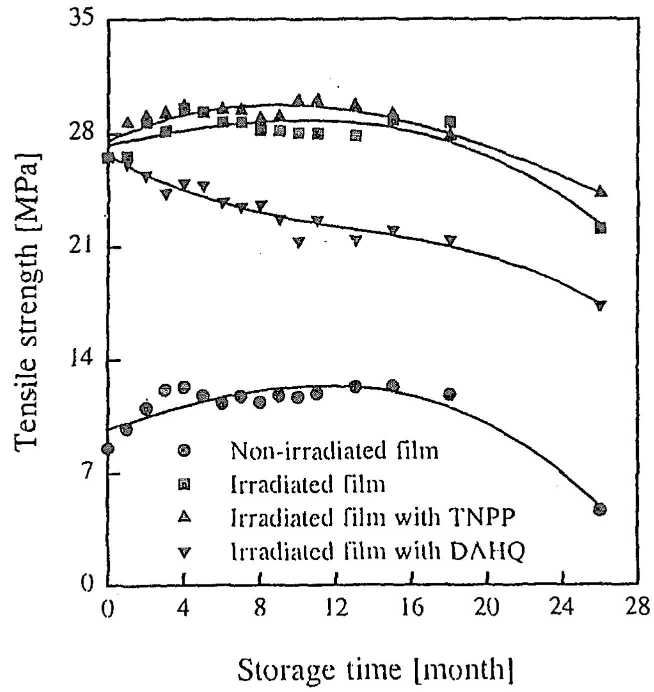


Fig. 7 Effect of storage time in air on the tensile strength of various types of rubber films.

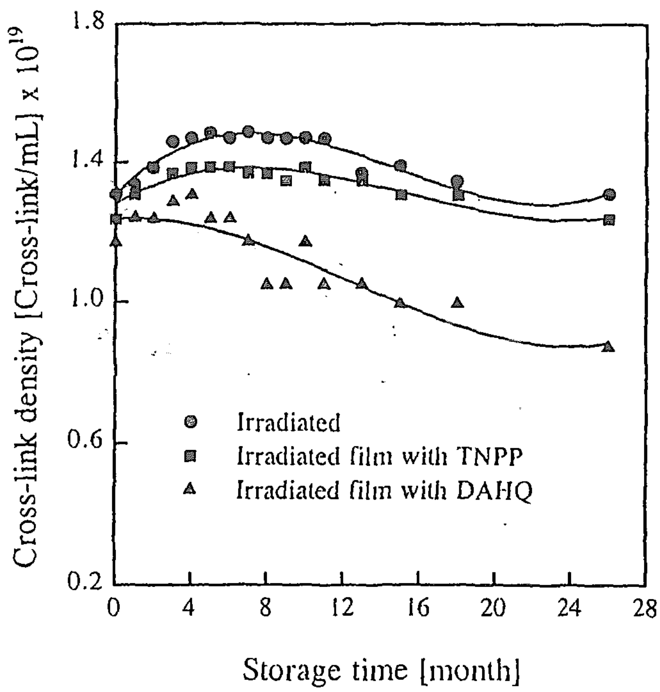


Fig.8 Effect of storage time in air on cross-link density of various types of rubber films.

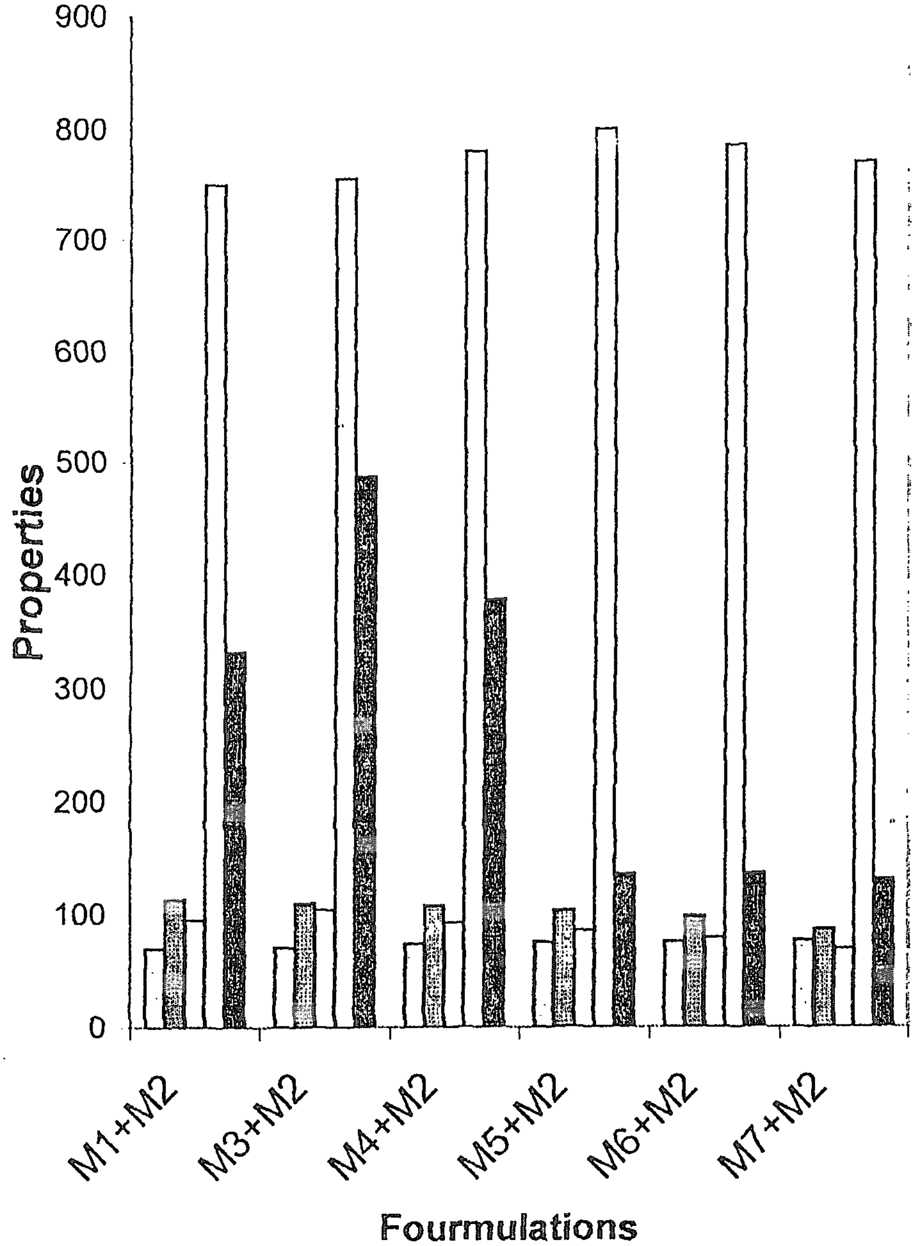
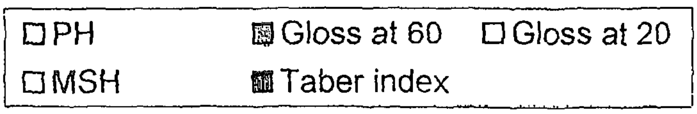


Fig.9 Curing of Surface Coating by UV radiation.



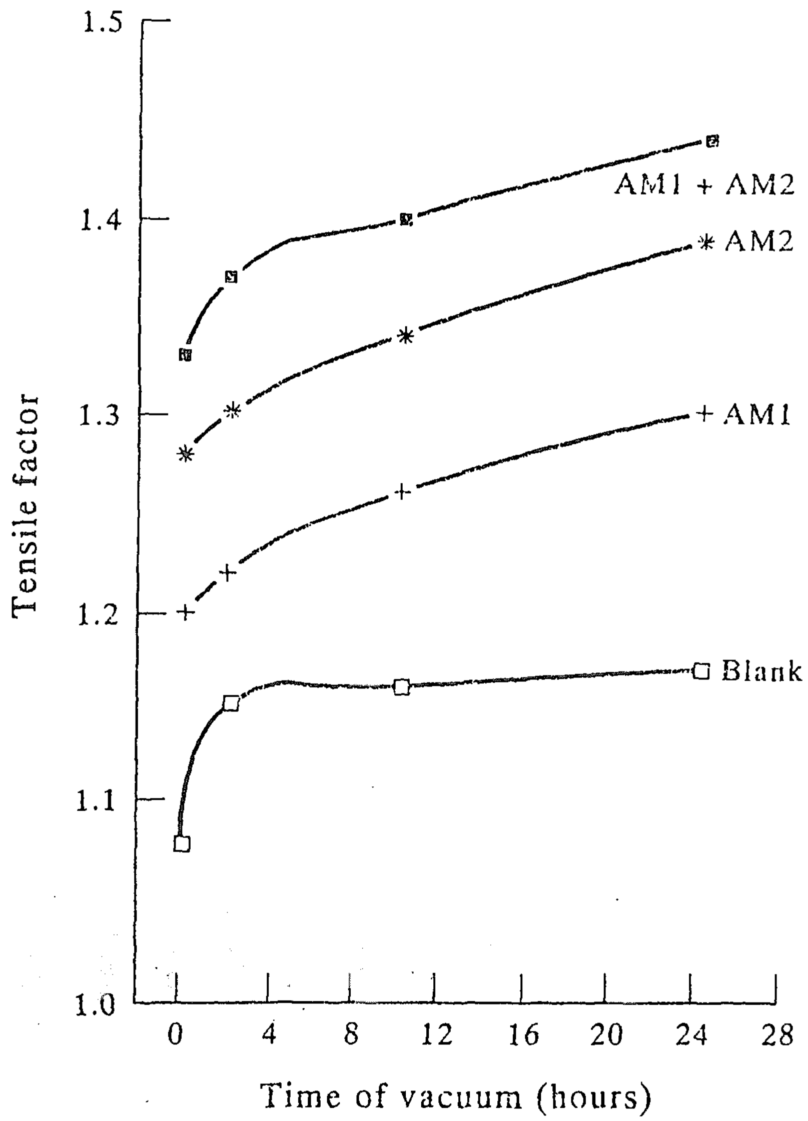


Fig.10 Tensile strength factor of the composites prepared with different impregnating solutions against vacuum time.(TS of simul = 3770 kg/m^2).