RADIATION PROCESSING OF POULTR

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SAMEVATTING

Gammabestraling besit die vermoë om die rakleeftyd van kommersieel geproduseerde hoenders te verleng deurdat dit mikroörganismes op die hoenderkarkas vernietig. Sulke behandelde karkasse het 'n rakleeftyd van 14 tot 21 d onder normale verkoelingstemperature, in vergelyking met onbehandelde karkasse met 'n rakleeftyd van 2 tot 4 d.

Alhoewel die vlak van *Salmonella*-besmetting op karkasse betreklik laag is, kon die organisme op 'n hoë persentasie karkasse aangetref word. Bestraling van die karkasse om rakleeftyd te verleng, sal dus ook hierdie patogene organisme vernietig. Selfs op karkasse wat kunsmatig met groot getalle van hierdie organisme besmet is, kon geen *Salmonella*-organismes na die toediening van 'n dosis van 3 of 5 kGy geïsoleer word nie.

Organoleptiës beoordeel, kon geen verskille tussen onbestraalde en bestraalde karkasse gevind word nie, selfs nadat die maksimum aanbevole dosis twee maal verhoog is.

Daar kan dus gesê word dat die bestraling van kommercieel gelewerde pluimveekarkasse met betreklik lae dosisse, in Suid-Afrika van aansienlike waarde kan wees deur (1) die aanvaarbare rakleeftyd aansienlik te verleng en (2) patogene bakterieë, indien teenwoordig, te vernietig.

ABSTRACT

Gamma irradiation, through its ability to inactivate micro-organisms, has been shown to effectively extend the shelf life of commercially slaughtered chickens from 2 - 4 d to 14 - 21 d under normal refrigeration temperatures.

Although a high percentage of carcasses were contaminated with *Salmonella*, the level of contamination was relatively low; the doses applied for shelf-life extension thus also served to eliminate this pathogen. Even when carcasses were artificially inoculated with *Salmonella* of levels several orders of magnitude higher than normal, the recommended radiation doses (3 or 5 kGy) were still capable of rendering the product 'pathogen free'.

Irradiated poultry could not be distinguished organoleptically from control samples, even when twice the maximum recommended dose was applied.

In conclusion, the irradiation of commercially produced poultry in South Africa with relatively low doses can be of significant benefit by (1) markedly extending the acceptable shelf life and (2) eliminating pathogenic bacteria present on the commercially available product.

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1. INTRODUCTION

The ability of ionising radiation to kill bacteria has been recognised for many years. In the case of food processing, the treatment may be divided into two categories, *viz.* sterilisation or pasteurisation. These categories are dependent solely upon the amount of radiation applied. For sterilisation, doses above 20 kGy* are generally utilised, but this application is not considered in this report. For pasteurisation, doses in the range 1 to 5 kGy are commonly employed.

In the case of fresh foodstuffs such as poultry and meat, two possible benefits may be derived from the application of pasteurising doses of irradiation. Firstly, an extension of the shelf life by a drastic reduction of initial bacterial numbers may be obtained, and secondly, pathogenic micro-organisms (e.g. *Salmonella*) which may be present are destroyed.

Poultry may be retailed in two forms, fresh or frozen. Under deep-freeze conditions (-15 to -20 °C), the meat remains saleable for many months as a result of the inability of spoilage bacteria to multiply at these low temperatures. However, a gradual deterioration in taste and texture of the flesh occurs with storage time. Consumers prefer fresh or chilled product where the carcass is maintained at refrigeration temperatures (0 to 5 °C) prior to and during the retailing operation. The acceptable shelf life of the product under these conditions is limited to only 2 - 4 d after slaughter.

Therefore, despite customer preference for the fresh product, the relatively short marketable life exerts a marked limitation on the

*kGy = kiloGray ≡ 100 krad

ratio of fresh to frozen poultry which a large producer can offer for sale. The principle reasons for this are the time required for distribution to, and the extremely short marketable life at, marketing outlets.

Distribution is particularly important in a large country such as South Africa where product from large, centralised production centres has to be conveyed over long distances to widespread marketing areas. The fact that the greatest poultry sales are made through supermarket chains, and that a high percentage of these sales is made just prior to week-ends, means that the retailer needs to understock to avoid high losses through putrefaction. Such understocking means inefficient marketing, since 'a full shelf sells best' is a well accepted supermarket principle.

The possibility of extending the market life to two weeks or longer would therefore be highly desirable. Such an extension would mean better and more efficient distribution, and would ensure the highest possible volume of sales at large retail outlets. If this process could also ensure a safer product by destroying pathogens present on the chicken carcasses, then it would be of even greater benefit to the poultry industry and consumer alike.

The shelf-life extension of poultry by gamma irradiation has been investigated elsewhere [2,8,10], but this study was carried out to ascertain the size of the extension, and the factors which affect it under South African conditions. The nature of the microflora, the incidence of pathogens and the total numbers of bacteria on the local product, may also differ from those in other countries, particularly in view of differences in climate, environmental conditions, diet, etc. These

parameters were cursorily investigated in a limited study, carried out on commercially prepared samples.

2. MATERIALS AND METHODS

Commercially slaughtered chicken carcasses were received from a large-scale poultry producer. The carcasses were treated within 24 h of slaughter and dressing.

Irradiation was carried out using the 'Research Loop' of the Commercial Medical Products Irradiator (AECL Limited) at Pelindaba (dose rate ~ 0,8 kGy/h).

Monitoring of the microbial flora on chicken carcasses was done in two ways, *viz.*:

(a) By swabbing 10 cm^2 of the skin area;

(b) by homogenising ~ 1 g of skin and meat.

After sampling, serial tenfold dilutions were plated using the pour-plate method. For total counts, nutrient agar (Difco) was used, and endo agar (Difco) was used for coliform counts. All dilutions were made with peptone water (Oxoid).

Incubation of all plates was carried out at 37 °C for 24 h.

The following selective media were used for identification purposes:

(a) *Staphylococcus* - Baird and Parker agar (Oxoid)

(b) *Enterobacteriaceae* - McConkey agar (Oxoid)
triple sugar iron agar (Oxoid)
Enterotube system (Roche)

(c) *Salmonella* - selenite broth (Oxoid)
brilliant green agar (Oxoid)
SS agar (Oxoid)
Enterotube system

All results given are the mean values of triplicate experiments.

3. RESULTS

3.1 Shelf Life

3.1.1 Reduction of microbial flora at different irradiation doses

In these experiments, freshly slaughtered chickens, commercially wrapped in plastic film (modified polyethylene), were irradiated with doses up to 5 kGy prior to storage at 2 °C. The surface bacterial contamination of the carcasses was monitored at regular intervals. The results, expressed in bacterial count/cm^2, are given in Table I.

TABLE I Reduction of bacterial numbers by different doses of irradiation

Storage time (days)	Dose (kGy)				
	0	2	3	4	5
1	$8{,}2 \times 10^5$	$< 10^2$	~ 50	< 10	< 10
6	$1{,}2 \times 10^8$	$1{,}7 \times 10^4$	~ 50	< 10	< 10
12	-	$4{,}5 \times 10^6$	3×10^3	1×10^2	< 10
20	-	-	5×10^6	2×10^5	5×10^3

From these results it can be seen that a great reduction of the bacterial flora occurs at radiation doses of between 2 - 5 kGy. After 20 d storage at 2 °C, the number of organisms surviving a 5 kGy dose had not yet reached the initial contamination level.

3.1.2 Relationship between total microbial numbers and organoleptic acceptability

From many experiments in which doses of 3 and 5 kGy and post-irradiation storage at 2 °C, 4 °C and 6 °C were applied, the following can be concluded:

(i) When the total bacterial counts exceeded 10^6 - 10^7 bacteria per cm^2 of chicken surface, the carcasses became organoleptically unacceptable (Fig. 1).

(ii) When monitoring of the microbial levels was carried out by bacterial counts of homogenised chicken meat and skin, the maximum acceptable contamination levels were found to be ~ 10^8 bacteria/g (Fig. 2).

3.1.3 Influence of post-irradiation storage temperature on the shelf life of chicken carcasses

As would be expected, the shelf life of chilled chicken carcasses is very dependent on the storage temperature (see Fig. 1). The recommended temperature for storage is 2 °C, but in practice this temperature is rarely maintained. At retail outlets the regulation of such temperatures is not reliable and is often closer to 6 °C. When using pasteurising doses of irradiation, the shelf life of the irradiated chicken carcasses is also determined by storage temperature (Table II).

TABLE II Influence of post-irradiation temperature on the shelf life of chicken carcasses

Temperature °C	Average shelf life (days)		
	Dose (kGy)		
	0	3	5
2	3	19	21
4	1	14	20
6	1	10	14

3.2 Isolation and Identification of Typical Contaminants on Chicken Carcasses

From the spoilage organisms generally encountered, a random selection was made for identification purposes. *Staphylococcus* spp., *Escherichia agglomerans*, *Proteus* spp. and Providence have been positively identified. The presence of *Pseudomonas*, *Streptococcus* and yeasts were also suspected. *Staphylococcus* was the only genus to survive an irradiation dose of 5 kGy.

By plating dilutions for total counts on endo agar, it was revealed that coliform organisms comprised between 1 and 10 % of the total bacterial load. Table III numbers of coliform organisms/cm^2.

TABLE III Incidence of coliforms and effects of storage temperature and irradiation on their survival and proliferation

Storage time (days)	Storage temperature of chicken carcasses					
	6 °C			2 °C		
	Control	3 kGy	5 kGy	Control	3 kGy	5 kGy
1	$2,2 \times 10^5$	negative	negative	$1,9 \times 10^5$	negative	negative
7	$6,7 \times 10^7$	$9,3 \times 10^1$	$1,7 \times 10^2$	$9,8 \times 10^6$	negative	negative
14	$> 10^7$	$1,1 \times 10^4$	$4,4 \times 10^4$	$> 10^7$	$5,5 \times 10^1$	$4,3 \times 10^1$
21	$> 10^7$	$> 10^6$	$1,4 \times 10^5$	$> 10^7$	$9,1 \times 10^3$	$3,7 \times 10^4$

Immediately after irradiation, no viable coliforms could be detected, but it is interesting to note that a recovery of these organisms occurs after prolonged storage at both temperatures. The recovered cells then multiply normally to constitute an important part of the microflora, especially at 6 °C.

3.3 Isolation and Frequency of *Salmonella* Contamination

Presumptive *Salmonella* colonies were isolated through an enrichment technique and identified using the Enterotube system and triple sugar iron agar. Eleven cultures isolated and identified in this manner were serotyped at the Veterinary Research Institute at Onderstepoort.

In a series of experiments during summer and the following winter, the incidence of *Salmonella* on chicken carcasses before and after irradiation was determined (Table IV).

TABLE IV Percentage of chicken carcasses contaminated with *Salmonella* organisms

	Summer			Winter		
	Control	3 kGy	5 kGy	Control	3 kGy	5 kGy
	25	-	-	8,5	-	-
	33	-	-	25	-	-
	58	-	-	67	-	-
	42	-	-	33,3	-	-
Average	39,5	-	-	33,5	-	-

It is significant that no *Salmonella* organisms could be detected after radiation doses of either 3 or 5 kGy.

During another survey, 60 % of chicken carcasses were found to be contaminated with *Salmonella*. After irradiation to 5 kGy, one carcass (out of 36) proved to be positive for *Salmonella* despite a zero incidence in the same batch given 3 kGy. This exceptional finding is attributed to a possible fault in the experimental procedure.

The decimal reduction dose, D_{10} (the dose necessary for 90 % inactivation), for some *Salmonella* cultures grown in Selenite broth was determined (Table V).

TABLE V Decimal reduction doses for three *Salmonella* serotypes

Irradiation temperature	Mean D_{10} (kGy x 10^{-2})*		
	S. typhimurium	*S. pensacola*	*S. lexington*
0 °C	35	40	50
25 °C	42,5	42,5	55,0

*Dose rate ~ 1,8 kGy/h

Mean D_{10} values determined for these cultures are in the same range as usually encountered for these organisms [4,5,6].

When stored for 24 h at 4 and 6 °C after irradiation, there was little or no recovery in bacterial numbers. There was a recovery at 25 and 37 °C. More detailed studies on the effects of radiation upon these organisms are being carried out and will be reported separately [7].

3.4 Inoculation of Sterilised Carcasses with *Salmonella* Cultures

Chicken carcasses sterilised by high doses of irradiation (25 kGy) were inoculated with three *Salmonella* serotypes, and after being

given moderate irradiation doses at ~ 4 °C, the carcasses were monitored for any surviving *Salmonella* organisms.

The organisms were applied to the surface of carcasses in two ways: firstly, by swabbing a 10 cm^2 area with a *Salmonella* broth culture, and secondly, by dipping a portion of skin and meat (~ 1 g) into a broth culture for 10 min. This portion of meat was then replaced in the carcass.

After irradiation, the original swabbed area was monitored and the piece of skin and meat homogenised to determine the numbers of organisms which survived the irradiation treatment. Results are shown in Table VI.

From these results it is evident that pathogenic bacteria, e.g. *Salmonella*, even if present on the chicken carcass in relatively large numbers, are eliminated by doses of 3 and 5 kGy.

3.5 The Microbial Load upon, and the Irradiation of Giblets

The giblets of chickens are expected to be more highly contaminated than the rest of the carcass because they are subjected to greater handling and because the contents of the gut could be spilt during the dressing operation.

Irradiated and non-irradiated chicken liver and stomach samples were homogenised, and dilutions plated. Results are shown in Figure 3. The maximum acceptable contamination levels for chicken liver and stomach kept at 6 °C were reached after 10 to 11 d after a 3 kGy dose. A dose of 5 kGy extends this time to 13 d. There is therefore no significant

TABLE VI Recovery of three *Salmonella* serotypes on the surface of chicken carcasses after irradiation

Monitoring method	Numbers of bacteria recovered (per cm^2 - swabbing; per gram - homogenising)								
	Control			3 kGy			5 kGy		
	S. typhimurium	*S. pensacola*	*S. lexington*	*S. typhimurium*	*S. pensacola*	*S. lexington*	*S. typhimurium*	*S. pensacola*	*S. lexington*
Swabbing	$1,8 \times 10^4$	$1,4 \times 10^4$	$3,7 \times 10^4$	--	--	< 10	--	--	--
Homogenising	$3,1 \times 10^4$	$2,3 \times 10^4$	$5,8 \times 10^4$	--	--	$< 10^{2*}$	--	--	--

*Lowest dilution counted - quantitative results unreliable

difference between the results obtained for the giblet samples and those obtained for homogenised skin and meat, as shown in Figure 2.

Salmonella organisms were isolated from 41 % of stomach and 31 % of liver samples tested. No *Salmonella* organisms were detected on any samples treated with either 3 or 5 kGy.

3.6 Delayed Irradiation

In practice, the possibility exists that the irradiation of freshly slaughtered chicken carcasses might be delayed. The effect of delayed irradiation and storage under unfavourable conditions on shelf-life extension was therefore investigated by storing chickens at room temperature (~ 25 °C) for 24 h before irradiation (Fig. 4). Monitoring of the microbial levels was carried out by the swabbing method.

After 24 h at room temperature, the carcasses had a definite 'off' odour and the contamination levels were far above the maximum acceptable level. After irradiation to 3 kGy, the viable microbial levels decreased by a factor of ~ 10^5. If stored at 6 °C (see Fig. 1), the 3 kGy irradiated carcasses would take four days, and carcasses that received 5 kGy, eight days, to reach the maximum acceptable contamination levels. However, this does not indicate an extension of shelf life, as the carcasses were regarded as organoleptically unacceptable after 24 h at room temperature.

3.7 Organoleptic Aspects of Irradiated Chicken-Meat

3.7.1 Taste-panel evaluations

Poultry was prepared for taste testing by the following methods:

roasting on a rotisserie, baking in foil, casseroling in the oven, and braising. No salt was added to samples used for organoleptic testing. Poultry was also used in seasoned dishes such as 'Chicken a la K. g' and tomato casserole.

Organoleptic testing was carried out on poultry irradiated with doses of 3, 5, 7,5 and 10 kGy, as well as on non-irradiated controls. A distinction was made between the white and dark flesh of the poultry during the tests. A panel consisting of at least ten tasters could not detect any significant difference using the triangle-ranking or scoring-test methods, even at the 10 kGy dose level.

3.7.2 Colour

No difference in the colour of the flesh of irradiated and non-irradiated samples was exhibited by poultry cooked according to the mass of the carcasses. In exceptional cases a pink discolouration occurred in both the irradiated and non-irradiated carcasses. The discolouration, which disappears after 15 - 30 min, is probably caused by red bone marrow leaking from the bone. This discolouration is also dependent on the cooking time.

4. DISCUSSIONS AND CONCLUSIONS

From these results it is evident that a marked extension of shelf life is achieved by the irradiation of carcasses. At 2 °C, carcasses irradiated with a 3 kGy dose can be kept for 16 d longer than the non-irradiated product. But even under adverse commercial conditions (i.e. storage at 6 °C), 3 kGy irradiated carcasses exhibit a 9 d shelf-life extension compared with non-irradiated controls.

Application of the higher radiation dose (5 kGy) resulted in a proportionally greater shelf-life extension. However, it is not recommended that carcasses be kept for more than about 21 d under chilled conditions, as they gradually become unacceptable due to autolysis after this time [9,10]. For this reason, and because of economic considerations, the 3 kGy dose is considered to give perfectly acceptable shelf-life extension.

Maximum acceptability limits related to the swabbing and homogenising sampling methods are in agreement with those reported elsewhere [1,2,3,8], *viz.* 10^6 - 10^7 bacteria/cm^2 and 10^8 bacteria/g.

As may be expected, the frequency of carcasses contaminated with *Salmonella* organisms seems to show a slight variation between summer and winter periods. Although the actual levels of *Salmonella* organisms on contaminated chickens could not be estimated, the high incidence (up to 60 %) of contaminated carcasses gives cause for concern.

The finding that no *Salmonella* organisms could be isolated from chicken carcasses after irradiation to 3 and 5 kGy is very significant, as *Salmonella* is regarded as a food-borne pathogen that could lead to human infection.

If present, pathogenic bacteria (e.g. *Salmonella*) are expected to occur in small numbers on a healthy, freshly slaughtered chicken carcass. With the inoculation experiments (section 3.4) it was proved that even if *Salmonella* organisms are applied in relatively large numbers to the surface of a chicken carcass, all these organisms are killed with a relatively low irradiation dose. Only in one instance (*S. lexington*) were any survivors found after a 3 kGy irradiation

treatment. This serotype is known to be more resistant to radiation that the other two serotypes tested [7].

It is evident that the lowest convenient temperature (0 - 2 °C) should be applied prior to, during and after irradiation. Irradiation treatment should be applied as soon as possible after slaughtering. Once spoilage has set in, the process cannot be reversed, although it was found that a considerable reduction in bacterial numbers was achieved when spoiled carcasses were irradiated. As with other agricultural products, these results emphasise the need to start the irradiation process with a high-quality product.

The irradiated meat could not be distinguished from non-irradiated samples, even where the maximum recommended dose had been applied.

In conclusion, the irradiation, with relatively low doses, of fresh, chilled chicken carcasses produced in South Africa, has been shown to be of significant commercial value (a) by markedly extending the shelf life, and (b) by eliminating pathogenic organisms present.

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6. REFERENCES

1. Barnes, E.M. Microbiological problems of poultry at refrigerator temperatures - A review. J. Sci. Fd Agric. (1976) v. 27 p. 777.

2. Ingram, M.; Thornley, M.J. Changes in spoilage patern of chicken meat as a result of irradiation. Int. J. Appl. Rad. Isot. (1959) v. 6 p. 122.

3. Kahan, R.S.; Howker, J.J. Retention of fresh chicken quality in refrigerated poultry using radiation and other techniques. Report at Third International Congress on Food Sciences and Technology, Washington D.C., 9 to 14 Aug 1970. 12 p.

4. Licciardello, J.J.; Nickerson, J.T.R.; Goldblith, S.A. Inactivation of *Salmonella* in poultry with gamma radiation. Appl. Microbiol. (1970) v. 19 p. 663.

5. Licciardello, J.J.; Nickerson, J.T.R.; Goldblith, S.A. Recovery of *Salmonella* from irradiated and unirradiated foods. J. Food Sci. (1970) v. 35 p. 620.

6. Mossel, D.A.A. Scaling-up of *Enterobacteriaceae* radication of frozen eviscerated poultry and frozen boneless meats. IAEA report R-491-F. 1971.

7. Niemand, J.G. *et al.* In preparation.

8. Pledger, R.A.; Chen, C. Microbiological aspects of radiopasteurised chicken. NYO report 3733/8. Oct. 1966. 72 p.

9. Rhodes, D.N. The radiation pasteurisation of broiler chicken carcasses. Br. Poult. Sci. (1965) v. 6 p. 265.

10. Thornley, M.J. Irradiation of poultry and egg products. International Atomic Energy Agency. Symposium on food irradiation, Karlsruhe, June 1966, p. 427 - 437.

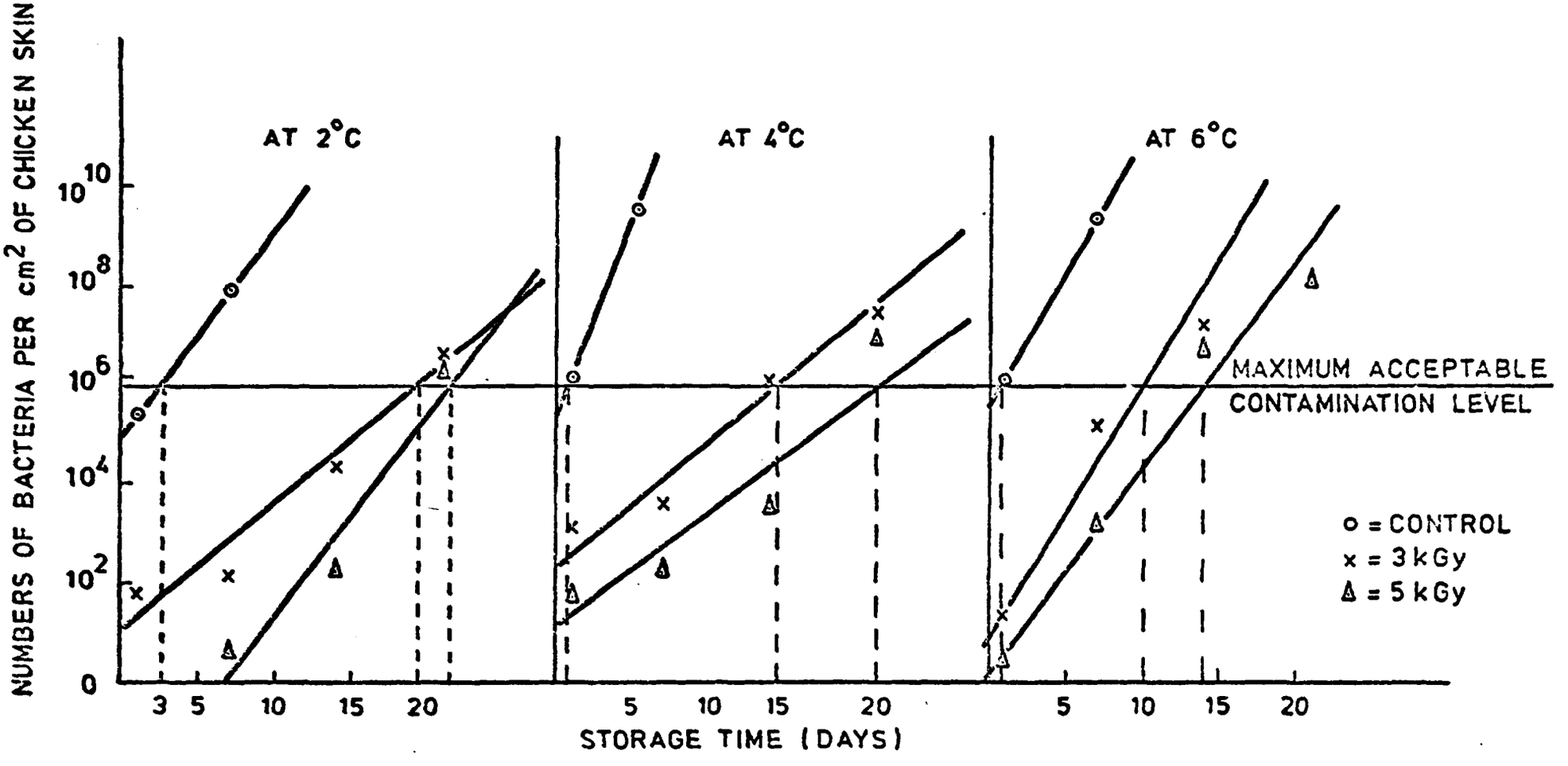

FIG. 1 EFFECT OF IRRADIATION ON THE SHELF LIFE OF CHILLED CHICKEN CARCASSES

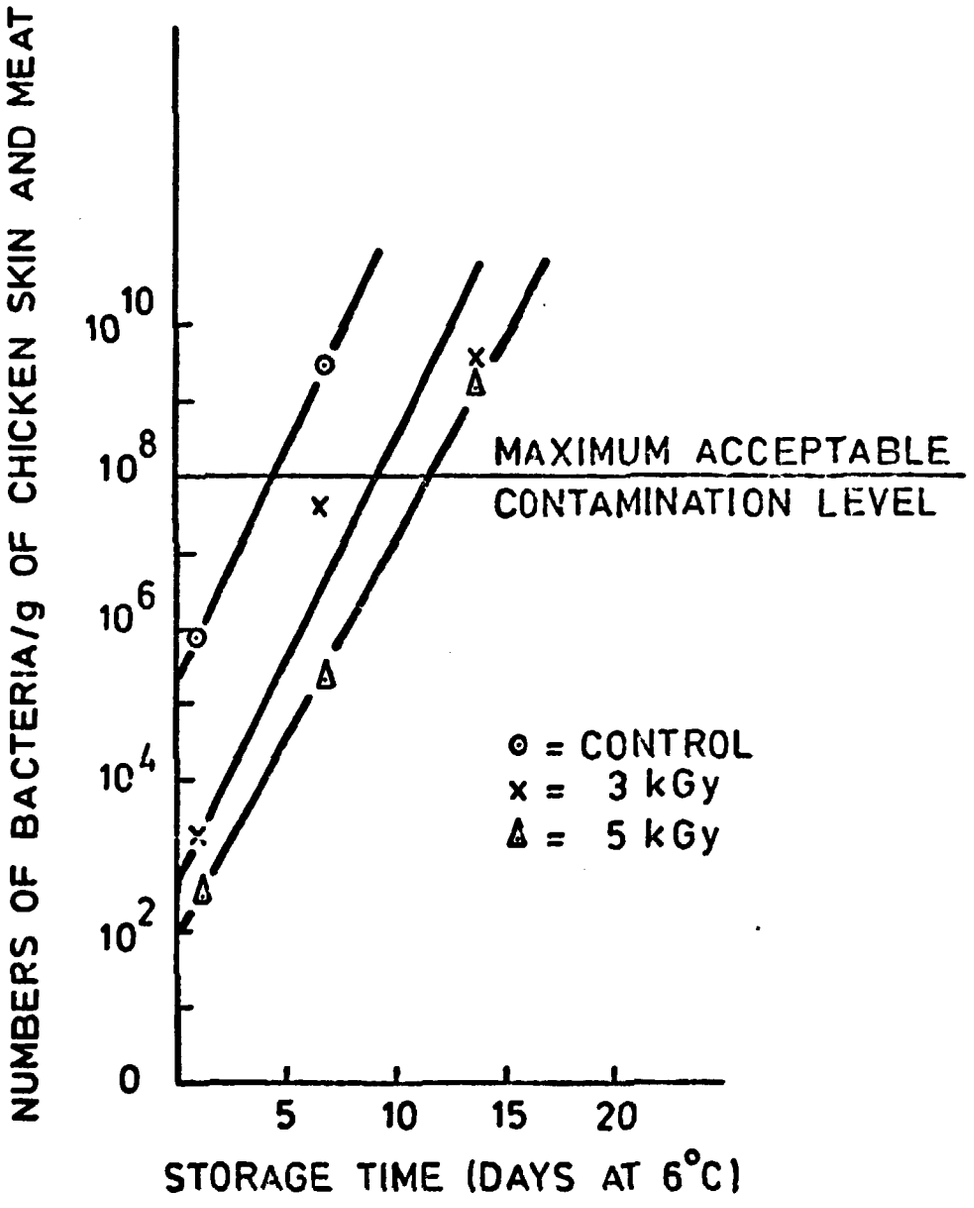

FIG.2 EFFECT OF IRRADIATION ON SHELF LIFE OF CHILLED CHICKEN CARCASSES

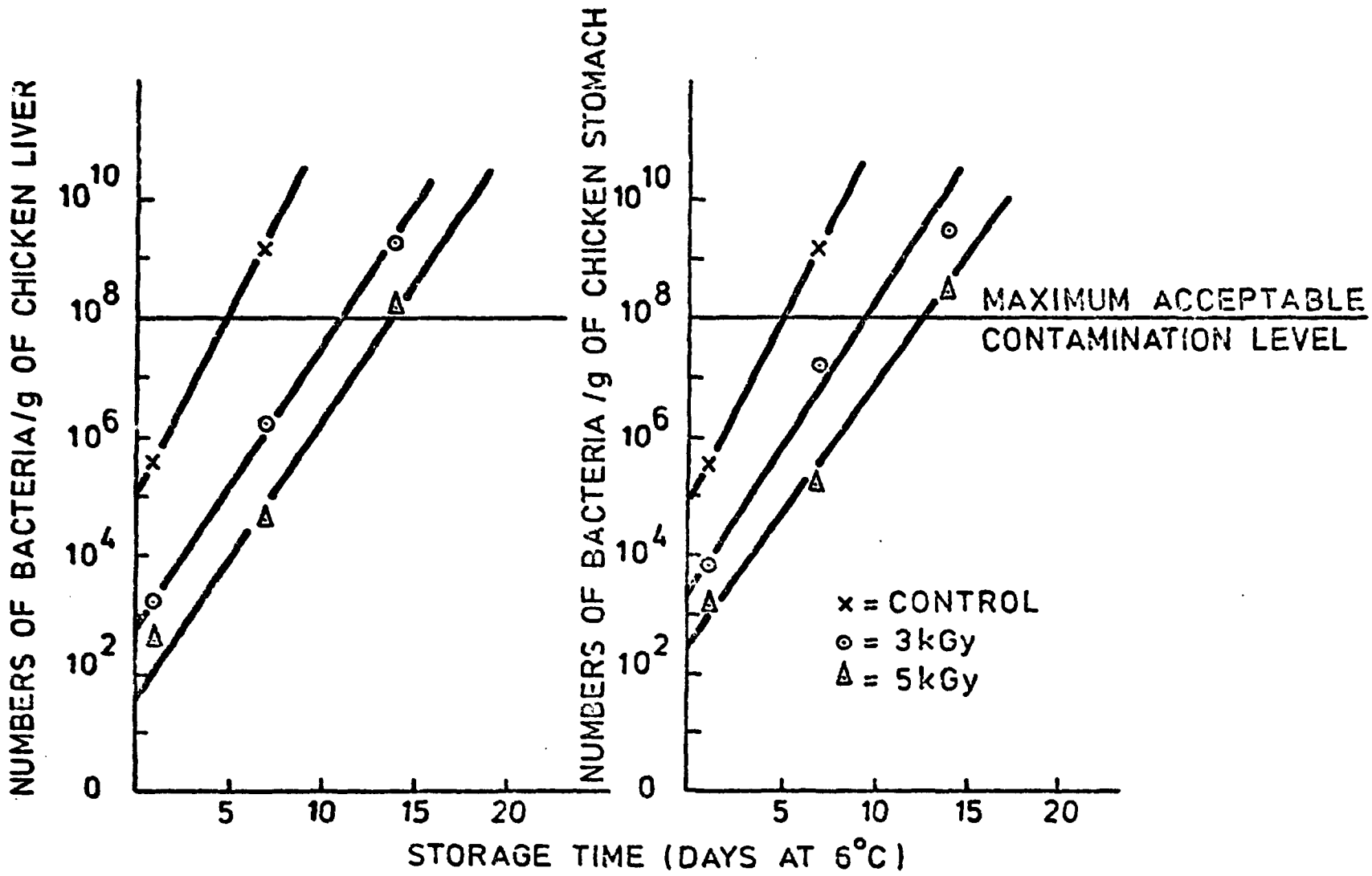

FIG. 3 THE EFFECT OF IRRADIATION ON THE MICROFLORA OF CHICKEN GIBLETS

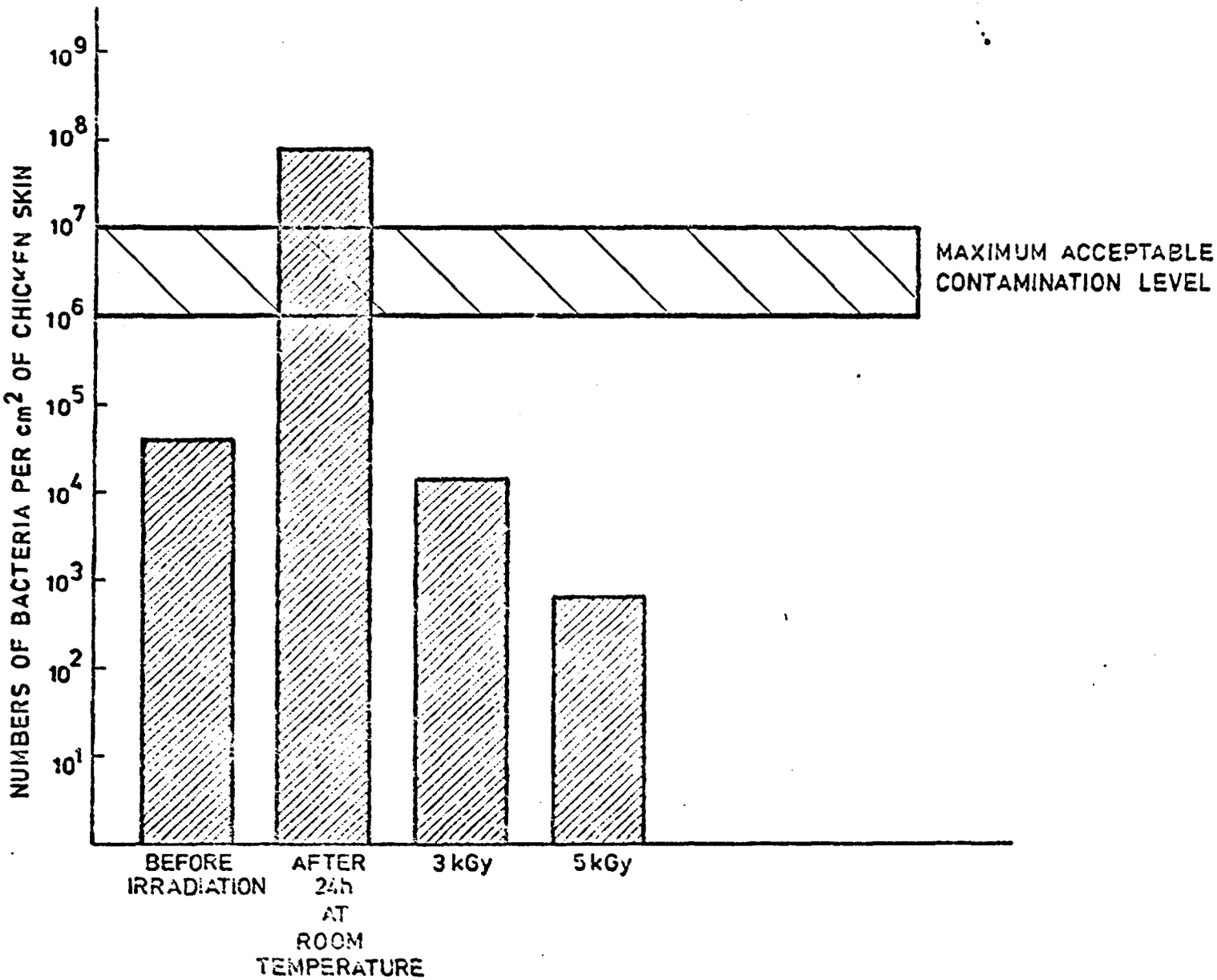

FIG. 4 EFFECT OF DELAYED IRRADIATION ON THE SHELF LIFE OF CHICKEN CARCASSES