

Survival of *Salmonella typhimurium* ATCC 14028 on the Surface of Chicken Legs or in Mechanically Deboned Chicken Meat Gamma Irradiated in Air or Vacuum at Temperatures of -20 to +20 C

**ABSTRACT** Response-surface methodology was used to develop predictive equations for the response of *Salmonella typhimurium* ATCC 14028 on the surface of chicken legs or within mechanically deboned chicken meat (MDCM) to the effects of gamma radiation doses of 0 to 3.60 kGy (100 krad = 1 kGy) at temperatures of -20 to +20 C in air or vacuum. A streptomycin-resistant mutant was used in these studies to allow accurate estimations of the surviving salmonellae in the presence of residual normal flora. This strain has been demonstrated to have no significant shift in its biological properties nor in its resistance to ionizing radiation. The response of *S. typhimurium* to gamma radiation was similar on both chicken legs and MDCM. The radiation was significantly more lethal to the bacterial cells at temperatures above freezing. The response-surface equations developed from the studies predict that the number of viable cells per gram of MDCM or per square centimeter of the surface of chicken legs would be reduced approximately 2.8 to 5.1 log units at 0 C by radiation doses within the range of 1.5 to 3.0 kGy. The results of the present studies are similar to those obtained previously with sterile mechanically deboned chicken meat.

(*Key words*: chicken, gamma radiation, temperature, atmosphere, *Salmonella*)

#### INTRODUCTION

The irradiation of chicken to control salmonellae and other foodborne pathogens was approved by the United States (*Federal Register*, 1990). The Food Safety and Inspection Service of the USDA petitioned the Food and Drug Administration (FDA) for approval of the use of ionizing-radiation treatments of retail packaged, frozen or fresh, uncooked poultry products to decrease the potential of food-borne illness from such food-borne pathogens as *Salmonella*, *Campylobacter*, and *Yersinia* (FDA, 1987). It is estimated that 35% of chicken carcasses in the United States may be contaminated with salmonellae (Dubbert, 1988). Treatment of chicken carcasses or meat with ionizing radiation has repeatedly been demonstrated to be an effective means to control foodborne human pathogens such as *Salmonella* (Previte *et al.*, 1970; Ley *et al.*, 1970; Licciardello *et al.*, 1970; Mulder, 1976; Mulder *et al.*, 1977; Hanis *et al.*, 1989; Thayer *et al.*, 1990), *Campylobacter* (Lambert and Maxcy, 1984), *Aeromonas* (Palumbo *et al.*,

1986), *Listeria* (Huhtanen *et al.*, 1989), and at much higher radiation doses *Clostridium botulinum* (Anellis *et al.*, 1977).

The effects of ionizing radiation on the organoleptic properties of fresh chicken depend on the temperature of irradiation, the absorbed dose, and the duration of refrigerated storage after treatment; cooking tends to minimize any differences between irradiated and unirradiated products (Coleby *et al.*, 1960; Mercuri *et al.*, 1967; Basker *et al.*, 1986; Hanis *et al.*, 1989). Recently, Thayer and Boyd (1990) reported the results of a study of the survival of *Salmonella typhimurium* when irradiated at temperatures from -20 to +20 C in the presence of air or *in vacuo*, in mechanically deboned chicken meat (MDCM) in the absence of competition from natural flora, using meat sterilized by gamma irradiation at -50 C *in vacuo*. Equations were developed from the results of the study to predict the response of *S. typhimurium* to gamma radiation in MDCM over the temperature range of -20 to +20 C, in the presence of air or vacuum, and at radiation doses from 0 to

3.6 kGy (1 Gy = 100 rad). The -20 to +20 C temperature range and the 0- to 3.6-kGy dose range were chosen to allow the development of predictive equations that would include the temperatures and permitted radiation doses that might be encountered in industrial practice. The purpose of the present study was to test the hypothesis that the presence of normal microflora in the MDCM would not alter the response of *S. typhimurium* to gamma radiation under conditions similar to those of the first study. A second purpose was to determine whether *S. typhimurium* cells on the surface of chicken skin would respond to gamma irradiation in the same manner as when they were in MDCM.

## MATERIALS AND METHODS

### Organisms

*Salmonella typhimurium* ATCC 14028 was used for these studies. A streptomycin-resistant mutant of *S. typhimurium* ATCC 14028 was isolated from the parent by adding an equal amount of fresh trypticase soy broth (TSB)<sup>1</sup> containing 2 mg/mL of streptomycin sulfate<sup>2</sup> to a 24-h culture at 35 C, which provided several streptomycin-resistant clones after continued incubation. One that will hereafter be designated as *S. typhimurium*<sup>Sr</sup> was found to grow well in the presence of 1 mg/mL of streptomycin sulfate. It was established by preliminary experimentation that the growth rate, cultural properties, taxonomic characteristics, and response to gamma radiation of *S. typhimurium*<sup>Sr</sup> were not altered from those of its parent strain. Because very large inocula were used in the present studies any back mutations to streptomycin sensitivity were not detectable by the methods used. The relative stability of the streptomycin resistance was demonstrated by the preliminary studies of the response of the streptomycin-resistant strain to gamma radiation and by the similarity of the results reported here to those reported earlier for the streptomycin-sensitive parent strain.

### Culture Maintenance

*Salmonella typhimurium*<sup>Sr</sup> was maintained and cloned on tryptic soy agar (TSA)<sup>3</sup> with incubation at 35 C. Cultural purity and identity were verified with Gram stain and API 20E strips.<sup>4</sup> One milliliter from an overnight (15 to 18 h) culture in TSB, incubated at 35 C, was used to inoculate 100 mL of TSB in a 500-mL baffled DeLong flask. Each inoculated flask of TSB was then incubated at 35 C with agitation at 150 rpm for 16 h. A 10-fold concentrated inoculum was prepared by centrifugation of the cells from TSB and then resuspended in 1:10 volume of sterile .1% peptone.<sup>3</sup>

### Mechanically Deboned Chicken Meat

Mechanically deboned chicken meat was obtained from a commercial manufacturer of poultry frankfurters. The meat was received in two commercial 18-kg lots and consisted of approximately 90% rib and 10% back meat. The average proximate analysis of this product was 65.3% moisture, 21.7% fat, and 25.0% protein. The MDCM was mixed well and subdivided into  $50.0 \pm .05$ -g lots, vacuum sealed in Number 400 Stomacher<sup>®</sup> polyethylene bags,<sup>5</sup> and then vacuum sealed in American Can Company Freshstuff<sup>®</sup> bags<sup>6</sup> (oxygen transmission .6 to .8 cm<sup>3</sup>/650 cm<sup>2</sup> per 24 h at 3.2 C and 90% relative humidity). Nonsterile chicken was stored at -20 C until used.

### Experimental Design

A response-surface design was used to develop a model for the effects of irradiation dose, irradiation temperature, and irradiation atmosphere on *S. typhimurium*<sup>Sr</sup> in nonsterile MDCM. One hundred and fifty grams of MDCM were inoculated with *S. typhimurium*<sup>Sr</sup> so as to give approximately 10<sup>9.7</sup> cfu/g. After inoculation, the MDCM and the inoculum were mixed using a model 400 Stomacher<sup>®</sup> for 90 s. Samples ( $5.0 \pm .05$  g) of the inoculated MDCM were aseptically transferred to sterile Number 400 Stomacher<sup>®</sup> bags. The MDCM was spread uniformly in a thin layer over an area of approximately 10 by 10 cm within the bag and heat-sealed either *in vacuo* or with air in the bag. Each Stomacher bag containing a sample was vacuum-packaged within an American Can Company Freshstuff<sup>®</sup> bag for additional protec-

tion against the absorption of oxygen by the vacuum-packaged samples and for greater microbiological security during the radiation treatment. The following temperatures and radiation doses were used for the study: -20 C, 0, 1.80, and 3.60 kGy; -10 C, .90 and 2.70 kGy; 0 C, 0, 1.80, and 3.60 kGy; +10 C, .90 and 2.70 kGy; and +20 C, 0, 1.80, and 3.60 kGy. Immediately following irradiation, all sample bags containing air were opened, flushed with air by flexing the bag open and closed, and resealed with air in the bag to remove any residual ozone from the sample. Ozone is produced by the reaction of ionizing radiation with air. The probability of picking up a streptomycin-resistant bacterium from the laboratory air during this brief procedure was considered to be extremely small. All samples were frozen at -20 C until analysis so that all samples would be subjected to freezing. An unirradiated control sample was used to determine the effect of freezing on the total colony-forming units of the *S. typhimurium*<sup>Sr</sup> in MDCM. The unfrozen samples averaged 3.8 times 10<sup>10</sup> cfu/g and the frozen samples 4.6 times 10<sup>9</sup> cfu/g of MDCM. The entire study was replicated twice.

A response-surface design study was conducted using *S. typhimurium*<sup>Sr</sup> and chicken drumsticks purchased from a local poultry store within 1 day of slaughter. The irradiation temperatures and doses were as described. The chicken legs were weighed and inoculated by dipping each leg into a 16-h culture containing 2.9 × 10<sup>9</sup> cfu/mL of *S. typhimurium*<sup>Sr</sup> in TSB. After inoculation, each chicken leg was placed in a Number 400 polyethylene Stomacher<sup>®</sup> bag and either vacuum sealed at -.99 bar or heat-sealed with air in the bag. Each Stomacher<sup>®</sup> bag containing a sample was vacuum packaged within an American Can Company Freshstuff<sup>®</sup> bag. All samples were assayed on the same day that they were irradiated and stored at 5 C until analysis. Those samples that contained air in the Stomacher<sup>®</sup> bag were opened immediately following irradiation. The experiment was replicated twice.

### *Irradiation*

Samples were irradiated in a self-contained cesium-137 gamma radiation source (135,000

Ci) producing a dose rate of .12 kGy/min. The dosimetry and dose distribution for this radiation source were described by Shieh *et al.* (1985). Routine dosimetry was conducted with ferrous sulfate-cupric sulfate dosimeters (Jarrett and Halliday, 1979). The samples were brought to the desired temperature before irradiation, and this temperature was maintained ± 2 C during irradiation by injection of the gas phase from liquid nitrogen. Because of the low heat capacity of gaseous nitrogen, the actual variation in sample temperature did not exceed .5 C. The samples were placed in a uniform portion of the radiation field and arranged to minimize any differences in the radiation dose. The mean deviation of the absorbed dose from the target dose was .038 kGy with a standard error of .018 kGy.

### *Microbiological Assay*

Samples were assayed for colony forming units by standard pour-plate procedures with serial dilutions in .1% Difco Bacto peptone.<sup>3</sup> The surface area of each chicken leg was estimated using the procedure of Goresline and Hough (1959), and 1.0 mL of sterile .1% peptone was added per square centimeter and used to wash the bacteria from each surface. The sealed Stomacher<sup>®</sup> bag containing the chicken leg and peptone was shaken vigorously 45 times by hand to wash off the salmonellae. The pour plates were prepared using TSA containing 1.0 g/L of streptomycin sulfate for *S. typhimurium*<sup>Sr</sup> and TSA for total aerobic colony-forming units. All petri plates were incubated for 24 h at 35 C. The colony-forming units on three petri plates at a dilution giving 30 to 300 colonies were counted using a New Brunswick Scientific Biotran II<sup>7</sup> automated colony counter and averaged.

### *Statistical Analysis*

Responses were expressed as the logarithm of the number of viable bacterial cells per gram or per square centimeter of surface area. These values were converted into survival values, that is the logarithm of [the number of colony-forming units (N) divided by the initial number of colony-forming units (N<sub>0</sub>)]. Regression techniques were used to fit second-order response-surface models to the data to allow prediction of the number of survivors following a given treatment (Draper and Smith, 1981). Graphical-

<sup>7</sup>New Brunswick Scientific Co., Inc., Edison, NJ 08818.

TABLE 1. Streptomycin-resistant Salmonella typhimurium colony-forming units per gram of mechanically deboned chicken meat after gamma irradiation at five temperatures in the presence or absence of air, Experiment 1

Dose <sup>1</sup> (kGy)	Irradiation temperature (C)	Air (n = 2)	Vacuum (n = 2) (Log cfu ± SD)	Combined (n = 4)
0	-20	9.62 ± .01	9.62 ± .02	9.63 ± .01
0	0	9.74 ± .04	9.57 ± .02	9.65 ± .10
0	+20	9.62 ± .01	9.78 ± .04	9.70 ± .10
.90	-10	8.39 ± .22	8.65 ± .06	8.52 ± .20
.90	0	7.73 ± .02	8.19 ± .09	7.92 ± .22
.90	+10	7.84 ± .02	7.99 ± .02	7.92 ± .08
1.80	-20	7.37 ± .13	7.83 ± .04	7.60 ± .28
1.80	0	7.03 ± 2.67	5.78 ± .06	6.40 ± 1.70
1.80	+20	4.78 ± .02	5.20 ± .08	4.99 ± .25
2.70	-10	4.49 ± .09	5.22 ± .41	4.85 ± .49
2.70	+10	2.14 ± .02	2.06 ± .15	2.10 ± .10
3.60	-20	3.62 ± .03	3.83 ± .02	3.73 ± .12
3.60	0	1.74 ± .44	1.88 ± .50	1.81 ± .39
3.60	+20	1.58 ± .03	1.52 ± 0	1.55 ± .04

<sup>1</sup>1 Gy = 100 rad.

ly, these results are presented as three-dimensional survival curves in which the logarithm of (N/N<sub>0</sub>) is plotted against radiation dose and temperature. Using this format, the destruction of one log of cells (1 D<sub>10</sub>) has the value of -1.0. Statistical calculations were performed with the General Linear Models procedure of the SAS<sup>®</sup> statistical package (Freund *et al.*, 1986; SAS Institute, 1987). Significance is reported at the .01 level. Results are expressed with two significant figures as all plate count data had two or more significant figures.

## RESULTS

The results obtained when *S. typhimurium*<sup>Sr</sup> was inoculated into MDCM and irradiated at temperatures from -20 to +20 C in the presence or absence of air are reported in Table 1. Analyses of covariances of these data did not reveal a significant difference between the effects of gamma irradiation in air versus those *in vacuo*; therefore, the entire data set was reanalyzed to generate a single response-surface equation. This is reported as Equation 1 in Table 2. The predictions of this equation

TABLE 2. Response-surface equations for the effects of gamma irradiation dose, and temperature (TEMP) on the survival of streptomycin-resistant Salmonella typhimurium (*S. typhimurium*<sup>Sr</sup>) in mechanically deboned chicken meat or on the surface of chicken legs and the normal aerobic mesophilic microflora on chicken legs

Equation number	Experiment	Equation <sup>1</sup>
1	1	Mechanically deboned chicken - <i>S. typhimurium</i> <sup>Sr</sup> Log <sub>10</sub> survivors = -.0943 - .0129 × TEMP - 1.8849 × kGy - .0182 × TEMP × kGy + .0008 × TEMP <sup>2</sup> - .0647 × kGy <sup>2</sup> R <sup>2</sup> = .947
2	2	Chicken legs - <i>S. typhimurium</i> <sup>Sr</sup> Log <sub>10</sub> survivors = -.0475 - .0133 × TEMP - 2.1139 × kGy - .0209 × TEMP × kGy + .0005 TEMP <sup>2</sup> + .1466 × kGy <sup>2</sup> R <sup>2</sup> = .960
3	3	Chicken leg - normal aerobic mesophilic flora Log <sub>10</sub> survivors = -.6852 - .0178 × TEMP - 1.8167 × kGy - .0056 × TEMP × kGy + .0008 × TEMP <sup>2</sup> + .3025 × kGy <sup>2</sup> R <sup>2</sup> = .838

<sup>1</sup>1 Gy = 100 rad.

TABLE 3. *Streptomycin-resistant Salmonella typhimurium* colony-forming units per square centimeter of chicken leg skin after gamma irradiation at five temperatures in the presence or absence of air, Experiment 2

Dose <sup>1</sup> (kGy)	Irradiation temperature (C)	Air (n = 2)	Vacuum (n = 2)	Combined (n = 4)
0	-20	6.94 ± .08	6.95 ± .00	6.94 ± .05
0	0	7.09 ± .15	7.05 ± .14	7.07 ± .12
0	+20	6.93 ± .01	6.78 ± .15	6.85 ± .12
.90	-10	5.90 ± .14	6.04 ± .01	5.97 ± .11
.90	+10	5.38 ± .55	5.24 ± .04	5.31 ± .33
1.80	-20	5.11 ± .08	5.34 ± .00	5.23 ± .14
1.80	0	2.21 ± .26	3.58 ± .36	2.90 ± .83
1.80	+20	2.13 ± .13	2.45 ± .42	2.29 ± .31
2.70	-10	2.75 ± .07	3.40 ± .33	3.08 ± .42
2.70	+10	1.88 ± .20	1.60 ± .06	1.74 ± .20
3.60	-20	3.16 ± .22	3.08 ± .40	3.12 ± .27
3.60	0	.70 ± .14	1.28 ± .24	.99 ± .37
3.60	+20	ND <sup>2</sup>	ND	ND

<sup>1</sup> 1 Gy = 100 rad.

<sup>2</sup>ND = No colony-forming units were detected by the plate count procedures used. A colony-forming unit value of 1.0 was arbitrarily used for statistical analysis.

are presented graphically in Figure 1. Analysis of variances for the results of irradiation indicated significant effects for irradiation temperature, dose, and temperature by dose interaction on the survival of *S. typhimurium*. Equation 1 predicts that an irradiation dose of 1.5 kGy would result in the inactivation of 1.63, 2.29, 2.78, 3.09, and 3.24 logs of *S. typhimurium*<sup>Sr</sup> per gram of MDCM irradiated at temperatures of -20.0, -10.0, 0, 10.0, and 20.0 C, respectively. Equation 1 predicts that an irradiation dose of 3.0 kGy would result in the inactivation of 3.47, 4.41, 5.17, 5.76, and 6.17 logs of *S. typhimurium*<sup>Sr</sup> per gram of MDCM irradiated at temperatures of -20.0, -10.0, 0, 10.0, and 20.0 C, respectively.

The results of irradiating *S. typhimurium*<sup>Sr</sup> on the surface of chicken legs are reported in Table 3. Analyses of covariances of these data did not reveal a significant difference between the effects of gamma irradiation in air versus those *in vacuo*, therefore, the entire data set was reanalyzed to generate a single response-surface equation. This is reported as Equation 2 in Table 2. The analysis of variances indicated significant effects for radiation dose, temperature, and temperature by dose interaction. The predictions of this equation are presented in Figure 2. Equation 2 predicts that an irradiation dose of 1.5 kGy would inactivate 1.80, 2.39, 2.89, 3.28, and 3.58 logs of *S.*

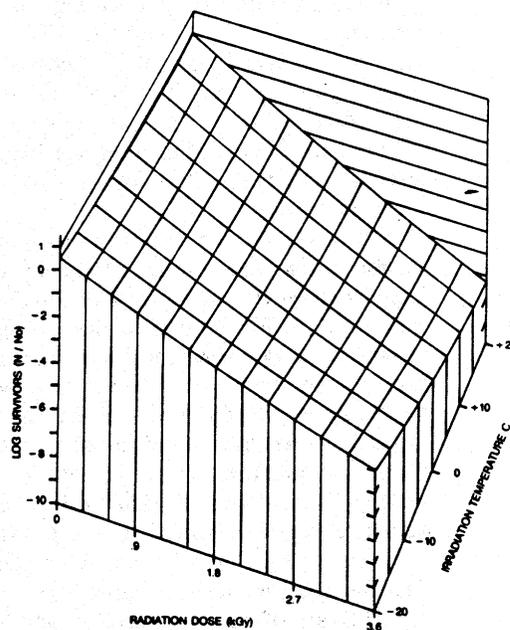


FIGURE 1. Prediction of Equation 1 for the inactivation of *Salmonella typhimurium*<sup>Sr</sup> on mechanically deboned chicken meat by gamma radiation administered within the temperature range of -20 to +20 C. 1 Gy = 100 rad.

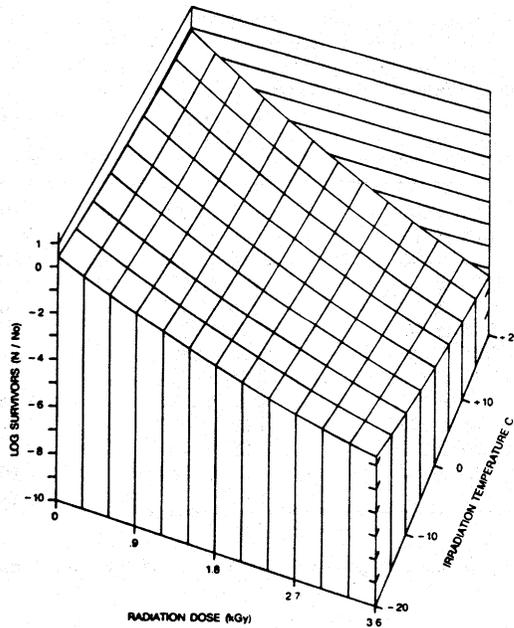


FIGURE 2. Prediction of Equation 2 for the inactivation of *Salmonella typhimurium*<sup>Sr</sup> on chicken legs by gamma radiation administered within the temperature range of -20 to +20 C. 1 Gy = 100 rad.

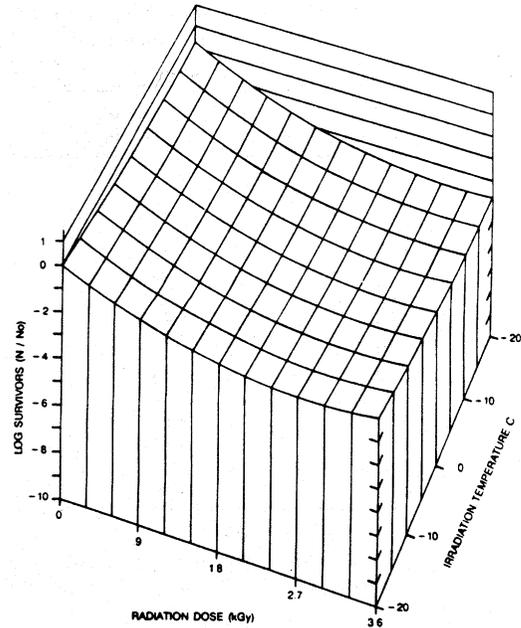


FIGURE 3. Prediction of Equation 3 for the inactivation of the normal aerobic mesophilic microflora of chicken legs by gamma radiation administered within the temperature range of -20 to +20 C. 1 Gy = 100 rad.

*typhimurium*<sup>Sr</sup>/cm<sup>2</sup> of chicken leg irradiated at temperatures of -20.0, -10.0, 0, 10.0, and 20.0 C, respectively. Equation 2 predicts that an irradiation dose of 3.0 kGy would inactivate 3.35, 4.26, 5.07, 5.78, and 6.39 logs of *S. typhimurium*<sup>Sr</sup>/cm<sup>2</sup> of chicken leg irradiated at temperatures of -20.0, -10.0, 0, 10.0, and 20.0 C, respectively.

The effects of gamma irradiation on the aerobic mesophilic normal flora of uninoculated chicken legs are reported in Table 4. As was the case for *S. typhimurium*<sup>Sr</sup>, significant effects were identified for both irradiation dose and temperature, but not for atmosphere. Examination of the raw results in Table 4 indicates that the initial aerobic mesophilic normal microflora was present at approximately 3 logs/cm<sup>2</sup> of skin surface and was almost completely eliminated by a dose of 3.6 kGy, providing it was administered above 0 C. The response-surface equation derived from the analysis of both the aerobic and vacuum-packed chicken legs is reported in Table 2 as Equation 3. The predictions of this equation are presented in Figure 3. Equation 3 predicts that an irradiation dose of 1.5 kGy would inactivate 1.90, 2.39, 2.73, 2.92, and 2.96 logs

of normal aerobic microflora/cm<sup>2</sup> of chicken leg at temperatures of -20.0, -10.0, 0, 10.0, and 20.0 C, respectively. Equation 3 predicts that an irradiation dose of 3.0 kGy would inactivate 2.41, 2.91, 3.41, 3.68, and 3.81 logs of normal aerobic microflora/cm<sup>2</sup> of chicken leg at temperatures of -20.0, -10.0, 0, 10.0, and 20.0 C, respectively. Responses of *S. typhimurium* or the normal flora to gamma radiation doses at various temperatures can be readily predicted using Equations 1, 2, and 3.

#### DISCUSSION

Considering that the total numbers of colony-forming units were very different in the MDCM and on the chicken legs, the results obtained with the two studies are remarkably similar. For example, at 0 C and a radiation dose of 1.5 kGy, Equations 1 and 2 predict the inactivation of 2.78 and 2.89 logs of *S. typhimurium*<sup>Sr</sup>; and Equation 3 predicts the inactivation of 2.73 logs of the normal mesophilic aerobic microflora of the chicken legs. All three response surfaces are similar in appearance and are significantly affected by the temperature of irradiation. Both studies

TABLE 4. Colony-forming units of normal mesophilic microflora per square centimeter of chicken leg skin after gamma irradiation at five temperatures in the presence or absence of air, Experiment 2

Dose <sup>1</sup> (kGy)	Irradiation temperature (C)	Air (n = 2)	Vacuum (n = 2)	Combined (n = 4)
0	-20	3.11 ± .90	3.44 ± .61	3.28 ± .74
0	0	3.59 ± .88	3.57 ± 1.07	3.58 ± .80
0	+20	3.05 ± .07	2.85 ± .10	2.95 ± .14
.90	-10	1.74 ± .06	2.42 ± .21	2.08 ± .41
.90	+10	.61 ± .86	.79 ± 1.12	.70 ± .82
1.80	-20	1.77 ± .08	1.95 ± .18	1.86 ± .15
1.80	0	.47 ± .14	1.03 NA	.65 ± .34
1.80	+20	.41 ± .16	.93 ± .37	.67 ± .38
2.70	-10	.56 ± 0	.92 ± .44	.74 ± .32
2.70	+10	ND <sup>2</sup>	ND	ND
3.60	-20	1.30 ± .77	1.39 ± .16	1.35 ± .46
3.60	0	.36 ± .51	.26 ± .37	.31 ± .37
3.60	0	ND	ND	ND

<sup>1</sup> Gy = 100 rad.

<sup>2</sup>ND = No colony-forming units were detected by the plate count procedure used. A colony-forming unit value of 1.0 was arbitrarily used for statistical analysis.

indicated that a dose of 3.0 kGy would inactivate approximately 5 logs of *S. typhimurium*<sup>Sr</sup> at 0 C. The similarity of these results indicates that the location of the *Salmonella* on the surface of the skin as opposed to mixed within the MDCM did not alter its resistance to gamma radiation.

The results described herein can be compared with those obtained by Thayer and Boyd (1990) in which the effects of gamma radiation on the survival of *S. typhimurium* in otherwise sterile MDCM were investigated. The predictions of the latter studies were essentially identical to those of the present study. For example, studies with sterile MDCM inoculated with *S. typhimurium* predicted that at 5 C a radiation dose of 1.5 kGy administered in air would inactivate 3.4 log cfu; and a dose of 3.0 kGy would inactivate 5.9 log cfu. The present study predicted the inactivation of 2.6 and 5.4 log cfu of *S. typhimurium*<sup>Sr</sup> at 5 C by radiation doses of 1.5 and 3.0 kGy, respectively.

Licciardello *et al.* (1970) reported the reduction of *S. typhimurium* per gram of comminuted chicken irradiated at 0 C to be 2 and 4 log cfu at doses of 1.5 and 3.0 kGy, respectively; the present study predicted the inactivation of approximately 3 and 5 log cfu of *Salmonella* in MDCM by radiation doses of 1.5 and 3.0 kGy. Previte *et al.* (1970) reported that the temperature of irradiation had the greatest influence on the resistance of salmo-

nellae to ionizing radiation. These authors reported D<sub>10</sub> values of 1.05, .65, and .54 kGy for cells of *S. typhimurium* RIA irradiated on chicken at -20, 4, and 22 C, respectively. These D<sub>10</sub> values would correspond to the inactivation of 1.4, 2.3, and 2.8 log cfu at -20, 4, and 22 C, respectively. Mulder (1982) reported a D<sub>10</sub> value of .67 kGy for *Salmonella panama* irradiated at 5 C on broiler carcasses. This value predicts the inactivation of 2.2 log cfu of *S. panama* by a radiation dose of 1.5 kGy compared with a prediction of the inactivation of 2.6 logs of *S. typhimurium* on chicken legs by the present study for the same dose.

Mulder (1976) estimated that a gamma radiation dose of at least 7.0 kGy would be required to reduce the number of *Salmonella*-positive, deep-frozen chicken carcasses to less than 1 in 10,000, and Hanis *et al.* (1989) concluded that a dose of 5 kGy would be insufficient to eliminate *S. typhimurium* from contaminated chicken carcasses when irradiated at -15 or +10 C. The results obtained in the present study do not contradict the predictions of either Mulder (1976) or Hanis *et al.* (1989) as a few very resistant cells will always be found in any large population. The present results do indicate that a high degree of protection against salmonellae contamination of chicken could be obtained by gamma radiation doses of 3.0 kGy or less.

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