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Irradiation for Control of Foodborne Pathogens on Meats and Poultry

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ABSTRACT

Research from the USDA, Agricultural Research Service is reviewed which defines the effects of atmosphere and irradiation temperature on control of the foodborne pathogens *Aeromonas, Listeria, Salmonella*, and *Staphylococcus*. The results indicate that both the temperature and atmosphere during irradiation of meats is important and that these pathogens can be greatly reduced in population by radiation doses of 3 kGy or less.

The Food Safety Research Unit at the Eastern Regional Research Center of the U.S. Agricultural Research Service (Philadelphia, PA) has the responsibility for conducting research to determine the efficacy and safety of irradiating red meats and poultry for the control of foodborne pathogens. This manuscript summarizes some of the results we obtained during studies of the responses of several important foodborne pathogens to gamma radiation.

Palumbo et al. (1986) evaluated the effects of gamma radiation on the survival of three clinical and two food isolates of *Aeromonas hydrophila* on bluefish and ground beef. This organism is a causative agent for diarrhea in humans and may be found on many types of retail foods such as fish, seafood (oysters, shrimp and scallops), red meats, and poultry and is capable of growth at refrigeration temperatures. At an irradiation temperature of 2°C the D-values (dose producing a 90% reduction in viable colony forming units) for the five isolates ranged from 0.14 to 0.19 kGy on blue fish or ground beef. *A. hydrophila* was more resistant to gamma radiation at a temperature of -15°C, and D-values of 0.22 to 0.34 kGy

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were observed. Irradiating fish or ground beef to doses of 1.5 to 3.0 kGy can eliminate this organism.

Huhtanen et al. (1989) irradiated seven strains of *Listeria monocytogenes* on mechanically deboned chicken meat (MDCM) with gamma radiation. The mean D-value at 2-4°C for the destruction of *L. monocytogenes* on MDCM was 0.77 kGy with a range of 0.59 to 1.03 kGy. Cultures developed from cells surviving a dose of 1.5 kGy were no more gamma-radiation resistant than those that had no previous exposure.

Thayer et al. (1990) investigated the effects of substrate and temperature of gamma irradiation on the survival of *Salmonella anatum, S. arizonae, S. dublin, S. enteritidis, S. newport*, and *S. typhimurium*. *S. enteritidis* was more resistant to gamma radiation on MDCM than were any of the other five strains. Radiation resistance was greater when the cells were suspended on MDCM than in buffer or brain heart infusion broth. The average D-value was 0.56 kGy for all six strains suspended on MDCM at an irradiation temperature of 2°C; the D-values ranged from 0.38 for *S. newport* to 0.77 kGy for *S. enteritidis*. The temperature of irradiation significantly affected the resistance of the cultures to gamma radiation.

Thayer and Boyd (1991a) determined the effect of gamma radiation dose, temperature, and atmosphere on the survival of *S. typhimurium* on MDCM in the absence of competing microflora. Responses were determined at temperatures of -20 to +20°C when the inoculated MDCM was packaged *in vacuo* or in the presence of air over a dose range of 0 to 3.6 kGy. Predictive equations were developed from these responses and tested through repeated studies. The equations predicted the response of *S. typhimurium* to gamma radiation under

the various experimental variables with a high degree of reliability. Radiation-sterilized meat was used for the study to eliminate the effect of competition and also to eliminate the necessity of using a selective culture media with its bias on the results. Both the temperature and the atmosphere in the sample containers during irradiation significantly affected the results. Gamma radiation was more lethal for *S. typhimurium* in the presence of air and at temperatures above freezing. The results indicate that the population of surviving *Salmonella* that receive a dose of 1.5 kGy at -20°C will decrease by 2.53 logs in air but by only 2.12 logs when irradiated *in vacuo*. A gamma-radiation dose of 3.0 kGy delivered at -20°C decreased the population by 4.78 logs and by 6.38 logs at +20°C.

Thayer and Boyd (1991b) investigated the effect of competing microflora on the survival of *S. typhimurium* on nonsterile chicken using a streptomycin-resistant strain to allow an assay on nonhibitory medium. The responses of *S. typhimurium* were very similar on chicken drumsticks and on MDCM. As observed previously, radiation lethality was significantly greater in nonfrozen samples. The presence or absence of air was not significant in this study. The results indicate that the number of viable cells of *S. typhimurium* per gram of MDCM or per square centimeter of the surface of chicken drumsticks would be reduced approximately 2.8 to 5.1 log units at 0°C by gamma radiation doses within the range of 1.5 to 3.0 kGy. This is the dose range that is currently approved for the irradiation of poultry. The results of this study validated the reliability of the predictive equations developed in the previous study and indicated that microbial competition did not have a major role in the survival of *S. typhimurium* on irradiated chicken.

Thayer, Songprasertchai, and Boyd (1991) discovered that the cells of *S. typhimurium* that survived a gamma radiation treatment on chicken were more sensitive to heat than were nonirradiated cells of this pathogen. The effect was directly proportional to radiation dose, and the lethality was much greater than that predicted from the additive effects of radiation plus heat. When the *Salmonella* were heated before the treatment with radiation no such increased lethality was observed. The increased sensitivity of the pathogen to heat following irradiation did not decrease even when the irradiated chicken meat was stored under refrigeration for six weeks. The authors concluded that because of this increased sensitivity to heat, such as that from cooking, irradiated chicken would have an even greater safety for the consumer than would be predicted from studies of reduction of pathogen populations by irradiation.

Szczawińska, Thayer, and Phillips (1991) investigated the ability of a constant uninjured challenge population of *Salmonella* to compete with reduced populations of normal indigenous microflora on MDCM following gamma irradiation treatment of the meat. For these studies MDCM was irradiated to 0, 1.25, or 2.50 kGy prior to inoculation with *S. dublin, S. enteritidis,* or *S. typhimurium*. Using this technique and constant inocula the variable for each study was the effect of the radiation dose on the indigenous microflora. Each sample was incubated aerobically for up to 9 days at 5, 10, or 20°C. The final populations of *S. dublin* and *S. typhimurium* were greater than the equivalent populations in samples that had not been irradiated before inoculation and stored at 10 or 20°C. The increases (less than 1 log) in these populations were, however, not considered to be signifi-

cant from a practical sense. The greatest risk for the consumer then would be from accidental post-irradiation contamination of the chicken.

No viable *S. typhimurium* were detected on chicken wings inoculated with 100 colony-forming units (cfu) following treatment with 1.8 kGy or greater gamma radiation doses at 5°C (Thayer et al., 1992). There was no recovery of injured *Salmonella* during a 3-day refrigeration of the irradiated chicken wings. When chicken wings were inoculated with 10 or 100 *S. typhimurium* per wing and irradiated to doses of 1.8 kGy or greater no viable cfu were found. Viable *S. typhimurium* were detected on chicken wings inoculated with either 1,000 or 10,000 cfu/wing following irradiation to 1.8 kGy but not after 2.7 kGy.

Thayer and Boyd (1992) discovered that gamma radiation doses of 0.26 kGy and 0.36 kGy, administered *in vacuo* at 0°C, inactivated 90% of log-phase and stationary-phase colony-forming units of *Staphylococcus aureus*, respectively, in MDCM. The presence or absence of air during irradiation did not produce significantly affect the results; however, the temperature during irradiation significantly affected the results. When MDCM was inoculated with approximately 10^4 colony-forming units per gram of *S. aureus* and gamma irradiated to 0, 0.75, 1.50, 2.25, or 3.00 kGy, viable cells were found only in the unirradiated samples and those that received 0.75 kGy. These results were not altered except for an increase in the populations by abusive storage of the samples for 20 hours at 35°C. Enterotoxin was found only in the non-irradiated samples following temperature abuse. This organism is very sensitive to gamma radiation and should be adequately controlled by the dose range currently approved for poultry irradiation.

The studies briefly summarized here have provided evidence that irradiation of meats with rather low doses of gamma radiation can provide significant protection for the consumer against possible infections or intoxications with *Salmonella, Listeria, Aeromonas,* and *Staphylococcus.*

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CONTROL OF FOOD BORNE BACTERIAL PATHOGENS BY TREATMENT OF MEAT WITH IONIZING RADIATION

PATHOGEN	TEMPERATURE	SUBSTRATE	D_{10} VALUE	REFERENCE
AEROMONAS HYDROPHILA	2°C	BEEF	0.14 - 0.19 kGy	(1)
CAMPYLOBACTER JEJUNI	0 - 5°C	BEEF	0.16 kGy	(2)
CLOSTRIDIUM BOTULINUM	-30°C	CHICKEN	3.56 kGy	(3)
LISTERIA MONOCYTOGENES	2 - 4°C	CHICKEN	0.77 kGy	(4)
SALMONELLA SP.	2°C	CHICKEN	0.38 - 0.77 kGy	(5)
STAPHYLOCOCCUS AUREUS	0°C	CHICKEN	0.36 kGy	(6)

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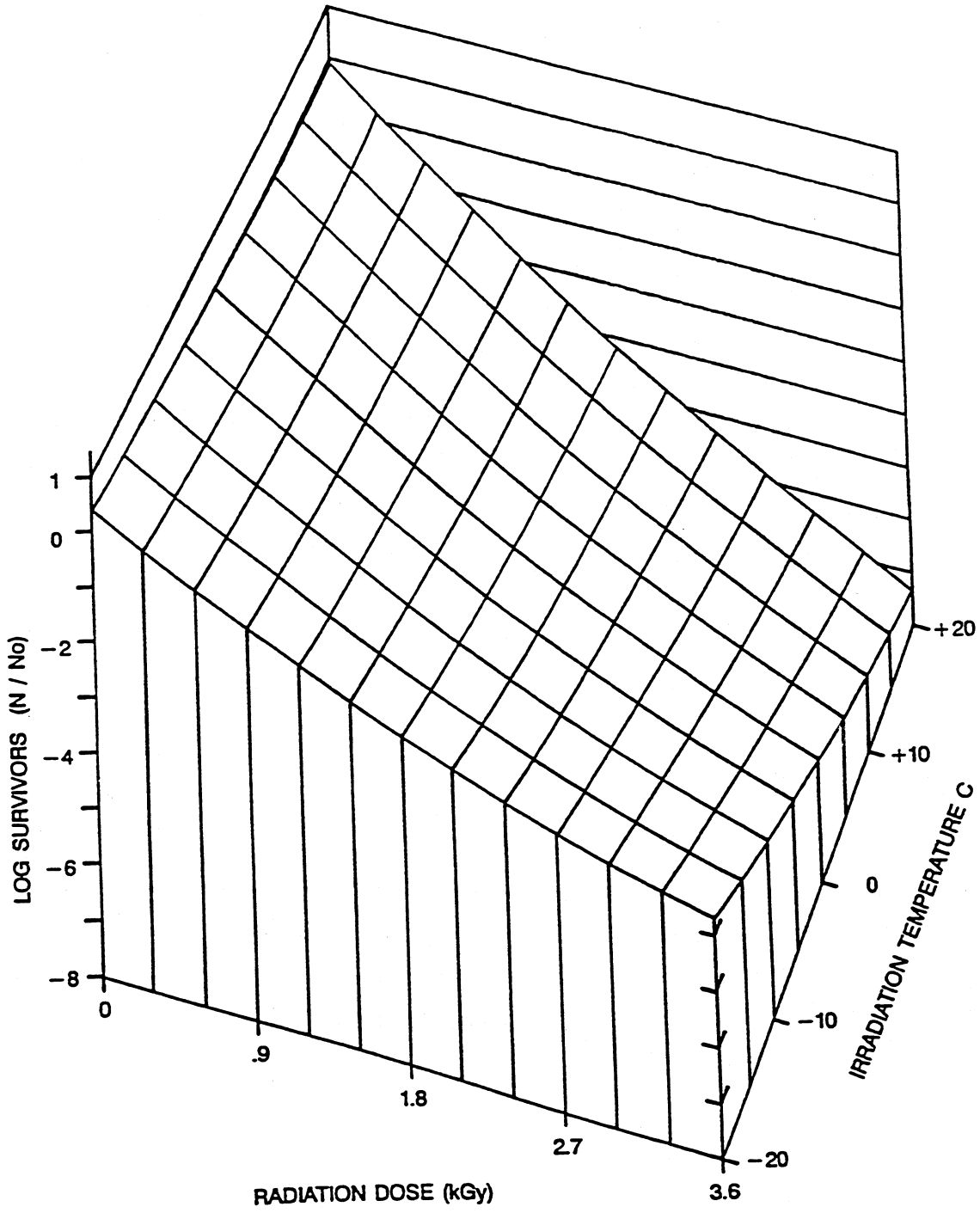
D-VALUES FOR SALMONELLAE IRRADIATED IN PHOSPHATE BUFFER, BRAIN HEART INFUSION, AND MECHANICALLY DEBONED CHICKEN

STRAIN	BUFFER	BHI	CHICKEN
S. ANATUM	0.116	0.288	0.520
S. ARIZONAE	0.184	0.244	0.444
S. DUBLIN	0.267	0.341	0.532
S. ENTERITIDIS	0.172	0.264	0.773
S. NEWPORT	0.152	0.212	0.378
S. TYPHIMURIUM	0.199	0.220	0.514

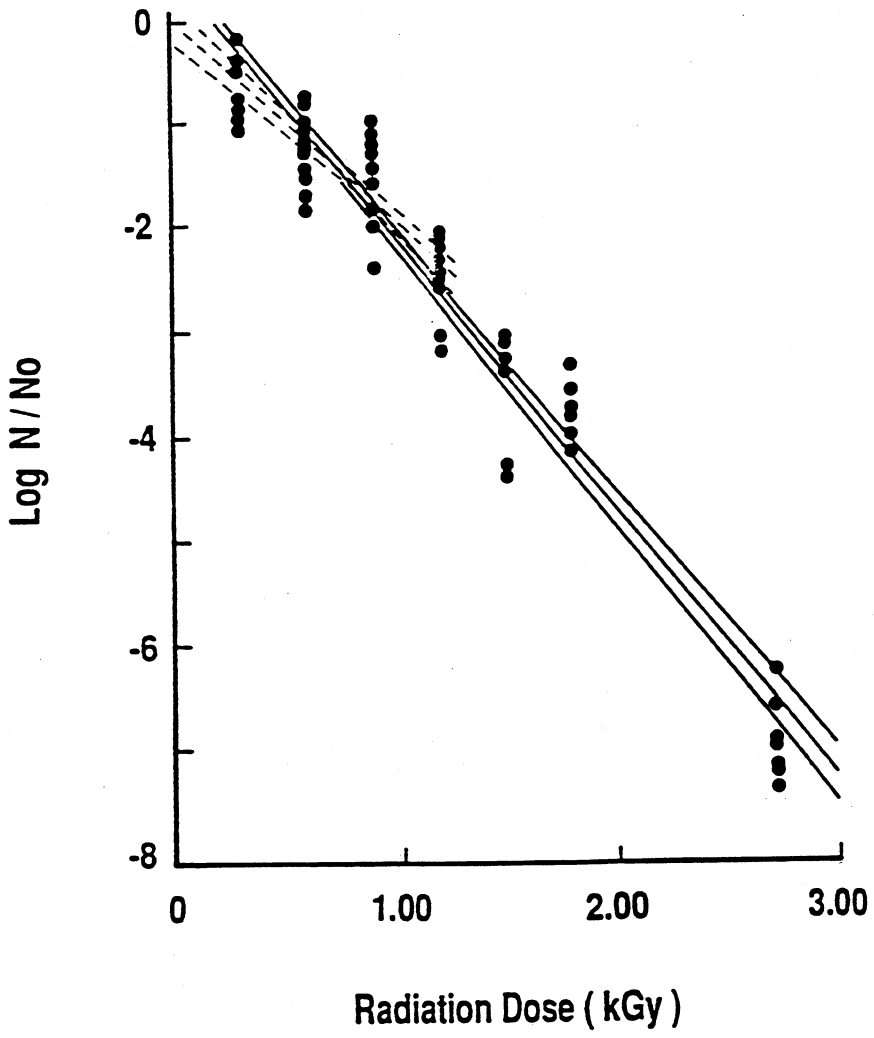
D-VALUE (KGY) CALCULATED FOR 0.30 TO 1.20 KGY.

SOURCE: THAYER ET AL., 1990. J. INDUST. MICROBIOL.

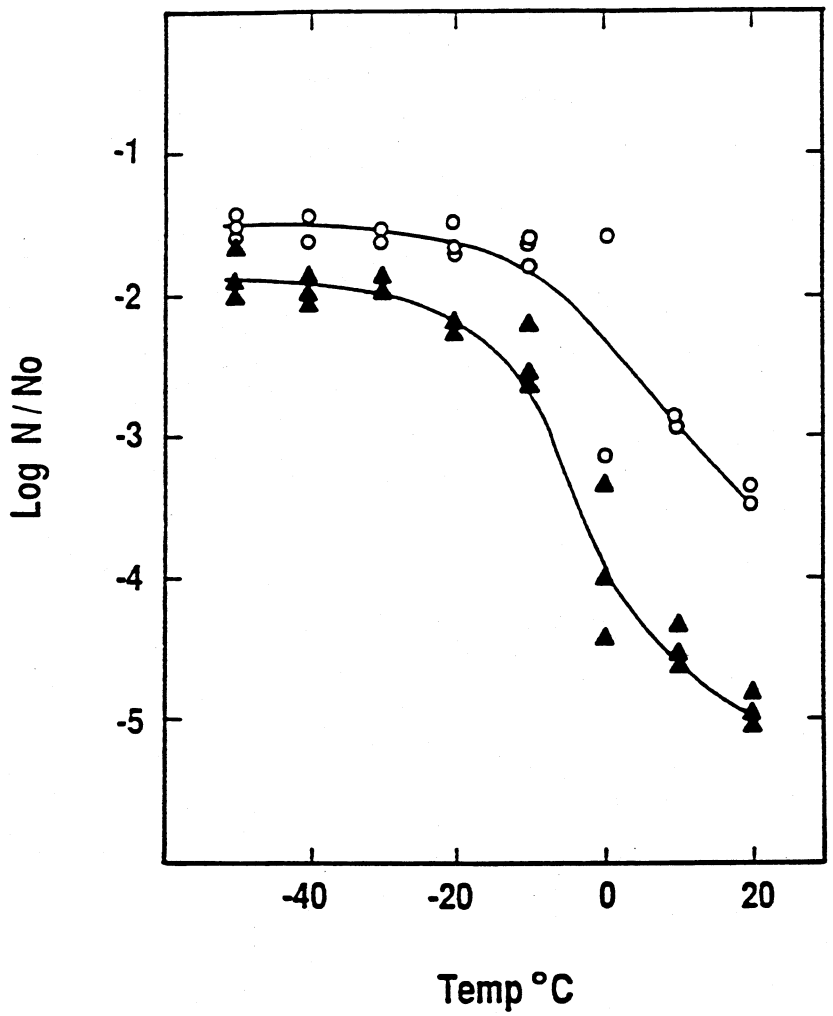
SURVIVAL OF *Salmonella typhimurium* IN STERILE VACUUM PACKED MECHANICALLY DEBONED CHICKEN MEAT



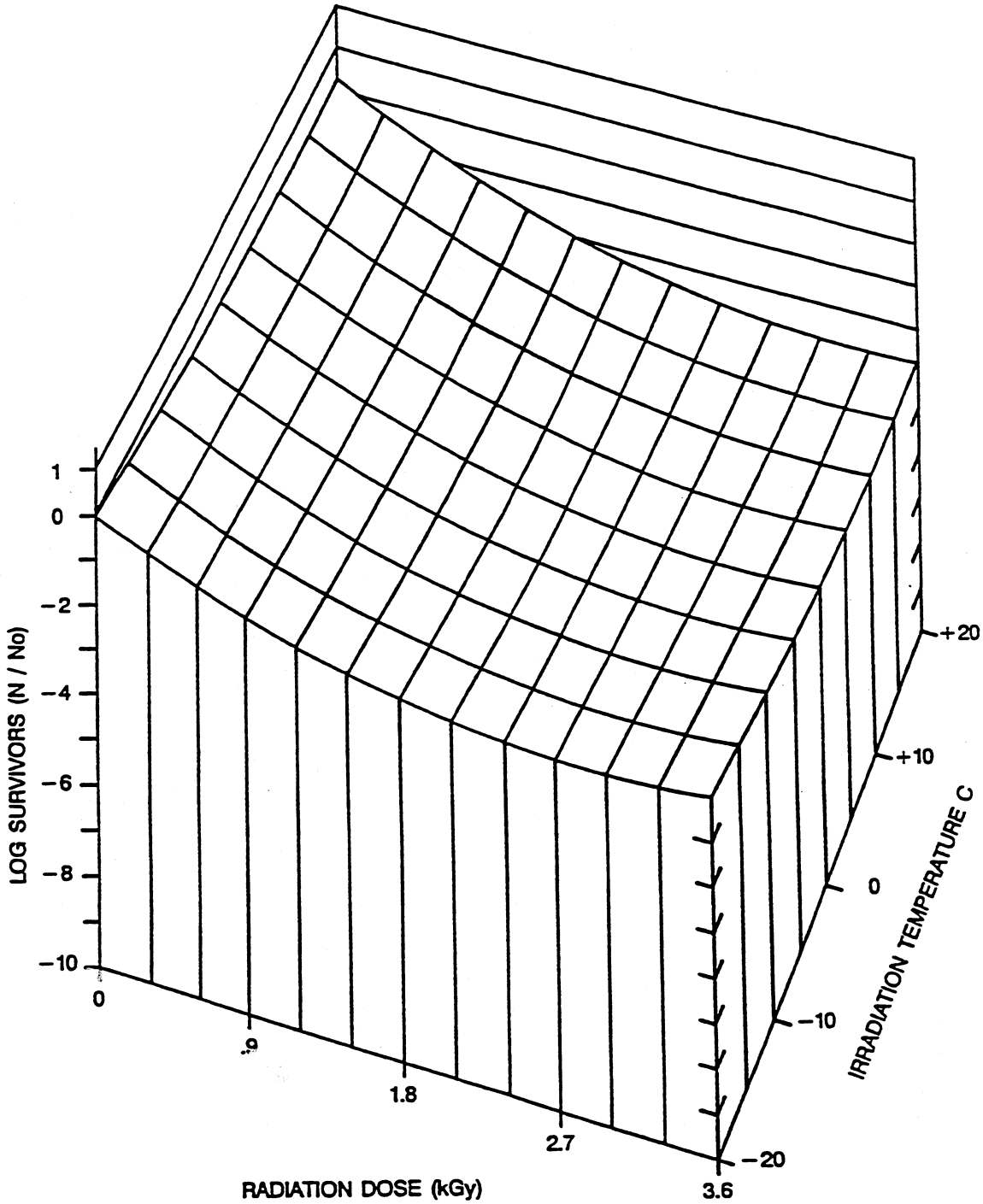
SURVIVAL OF *Salmonella typhimurium*
IN MECHANICALLY DEBONED CHICKEN MEAT



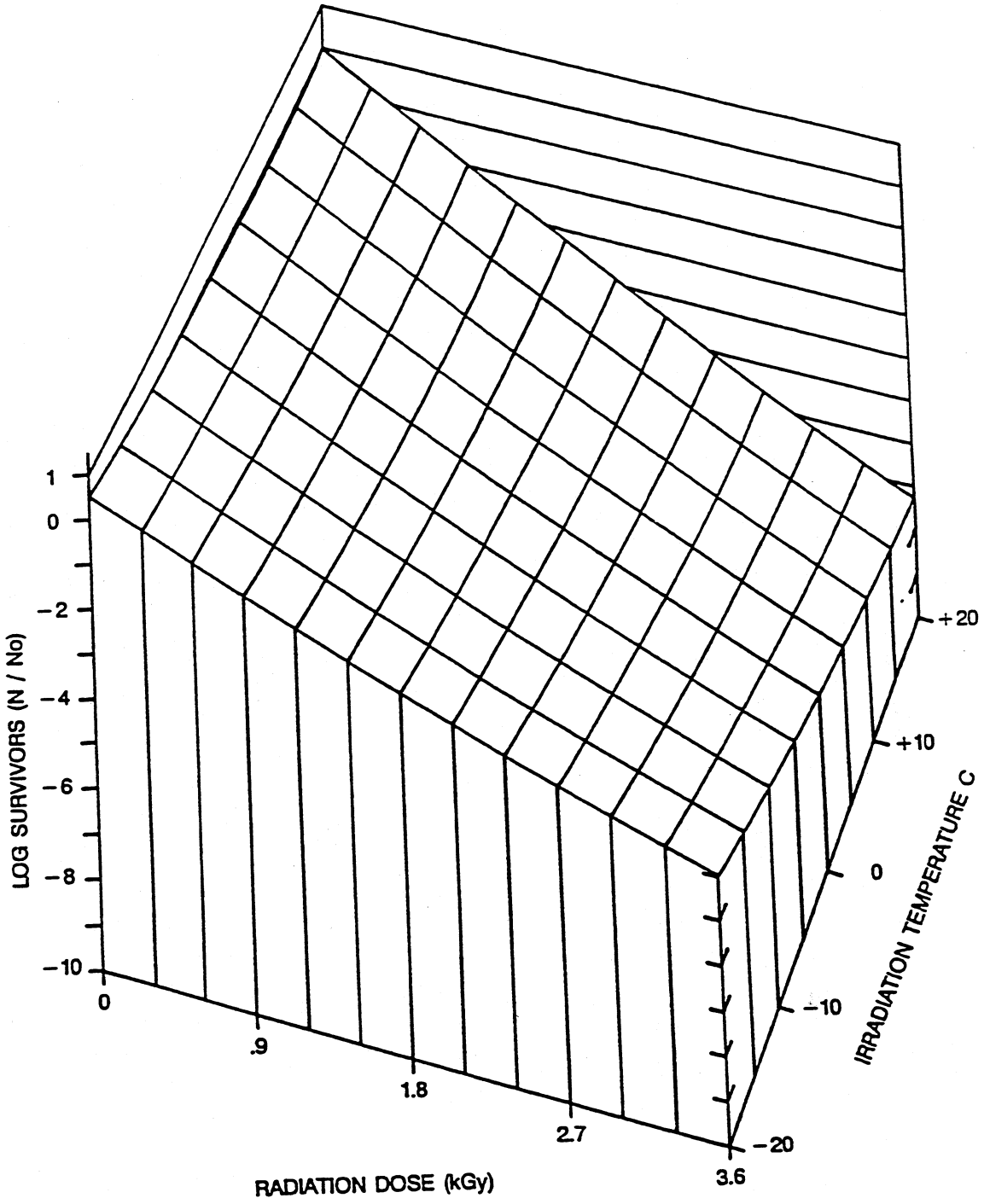
EFFECT OF IRRADIATION TEMPERATURE ON SURVIVAL OF
Salmonella typhimurium and Salmonella enteritidis



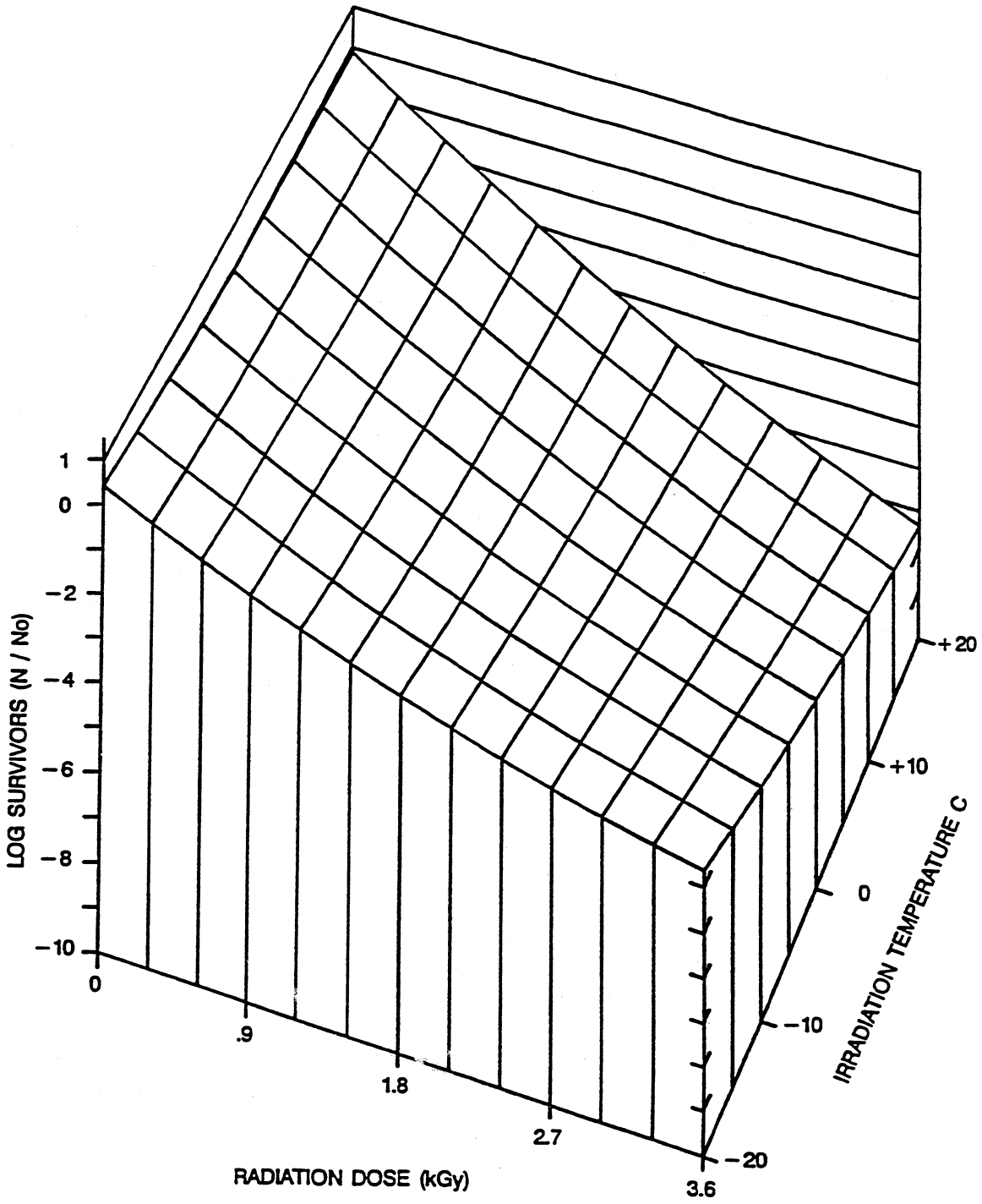
SURVIVAL OF NORMAL MICROBIAL FLORA
ON CHICKEN LEGS

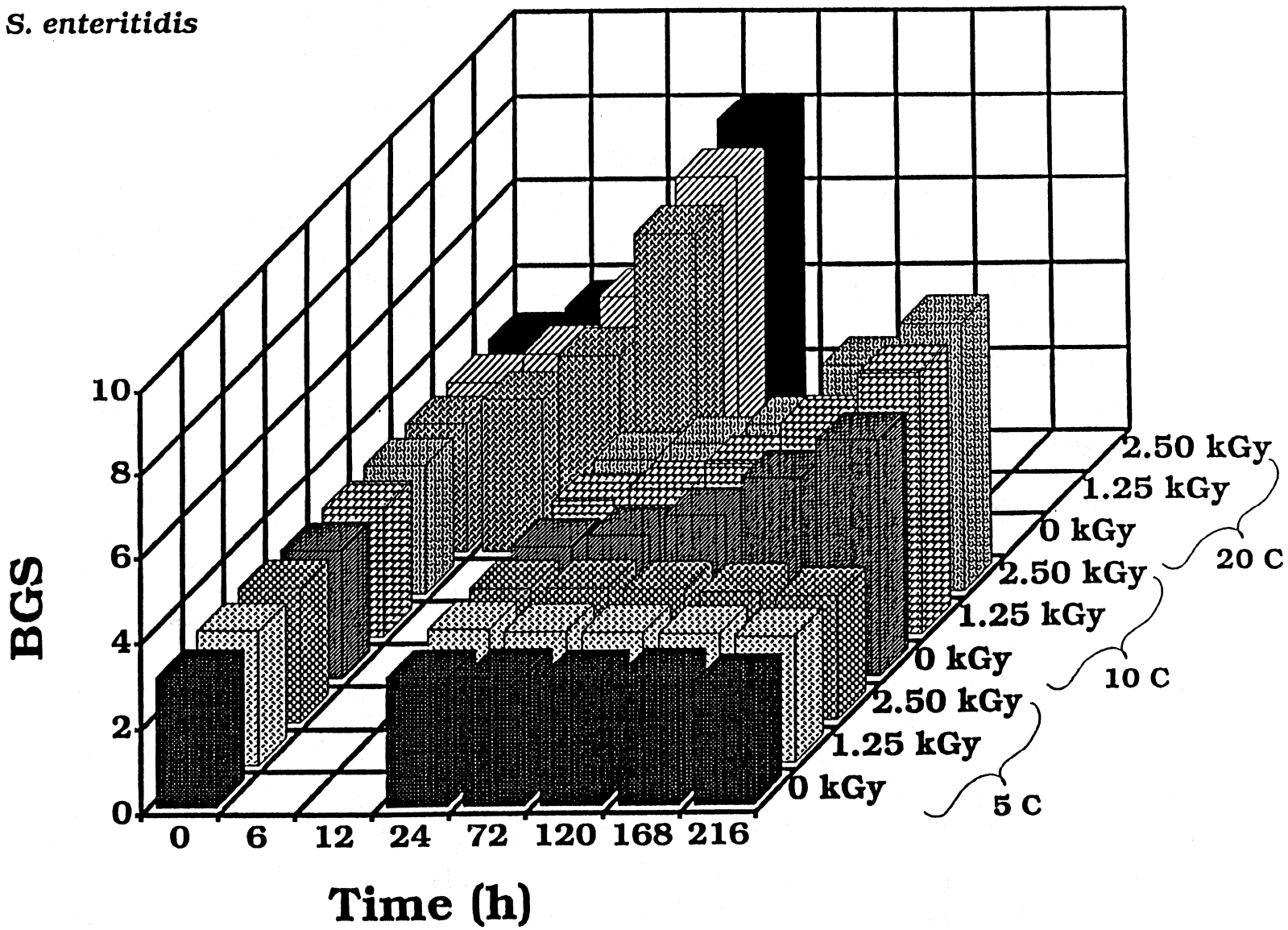


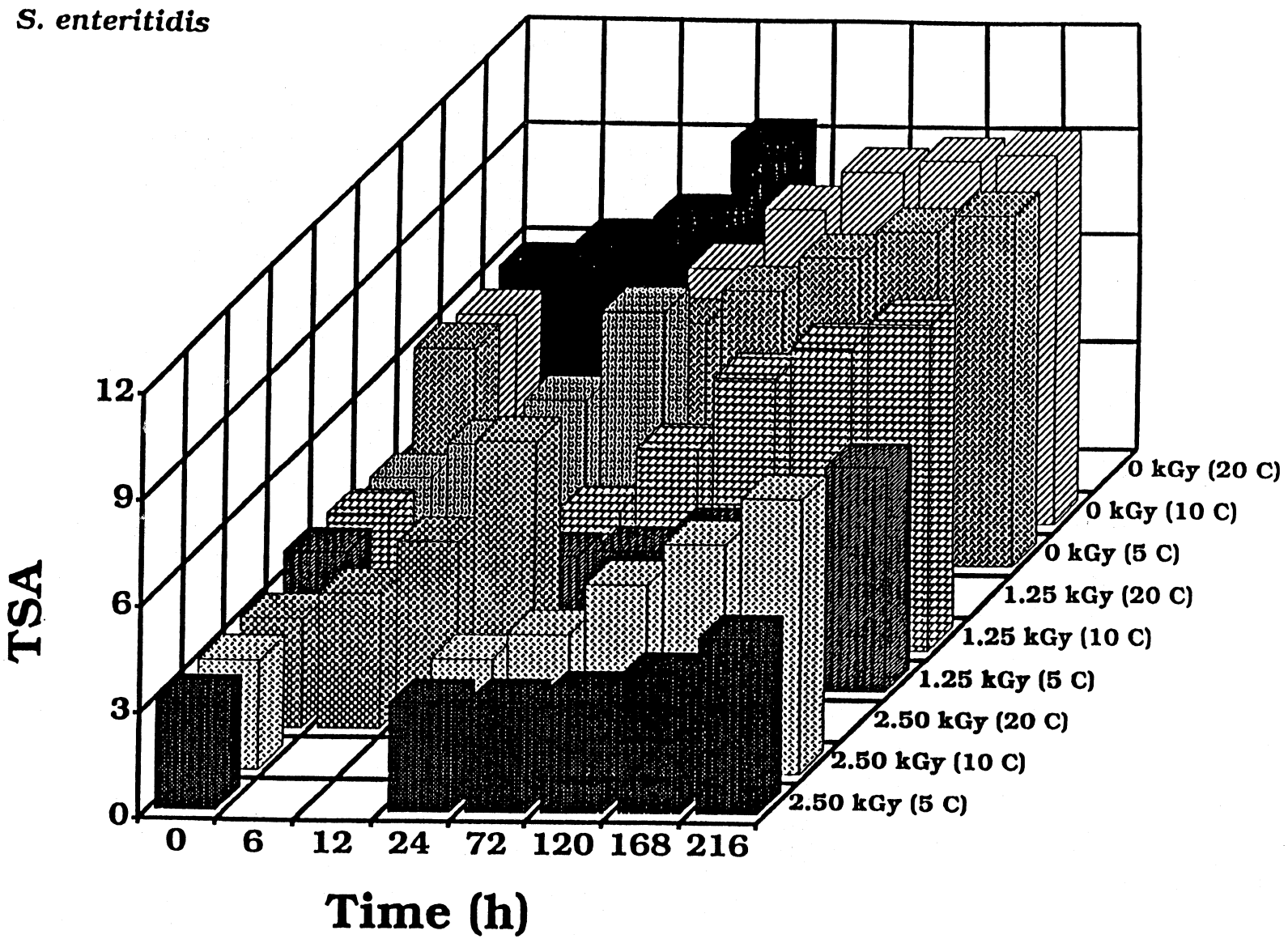
SURVIVAL OF *Salmonella typhimurium* ON
MECHANICALLY DEBONED CHICKEN MEAT



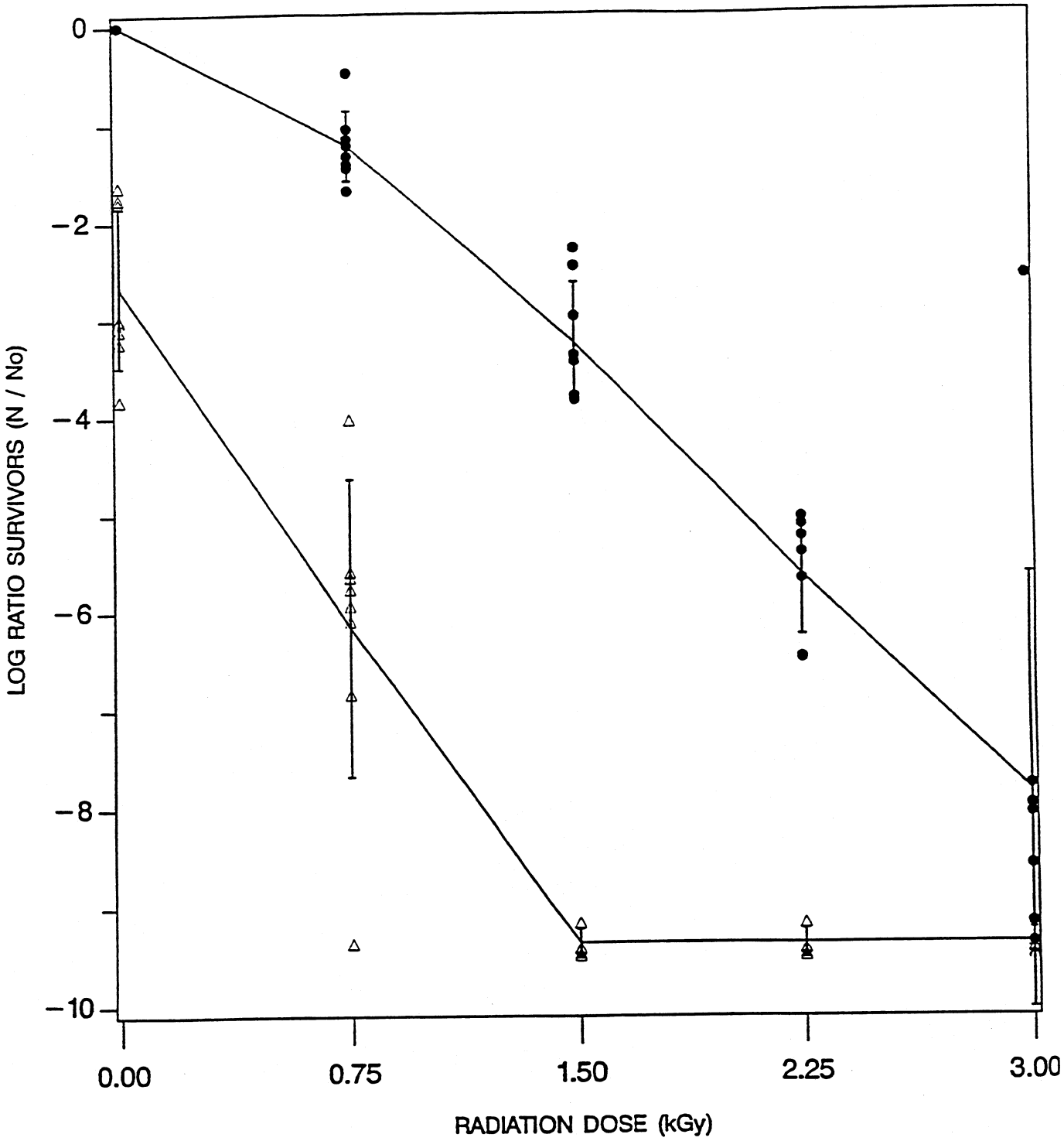
SURVIVAL OF *Salmonella typhimurium* ON CHICKEN LEGS

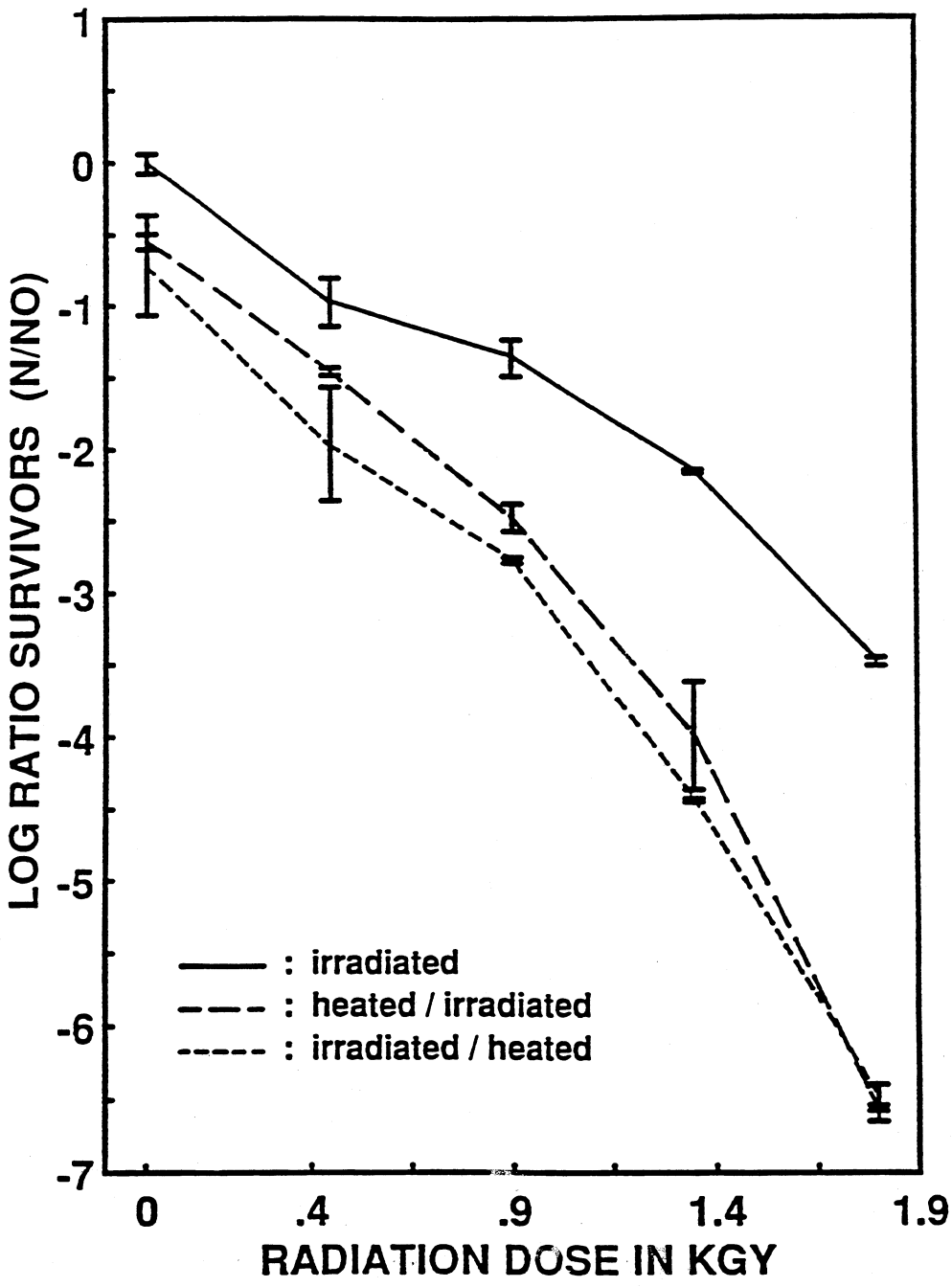



S. enteritidis
BGS
10
8
6
4
2
0
0
6
12
24
72
120
168
216
Time (h)
2.50 kGy
1.25 kGy
0 kGy
20 C
2.50 kGy
1.25 kGy
0 kGy
10 C
2.50 kGy
1.25 kGy
0 kGy
5 C

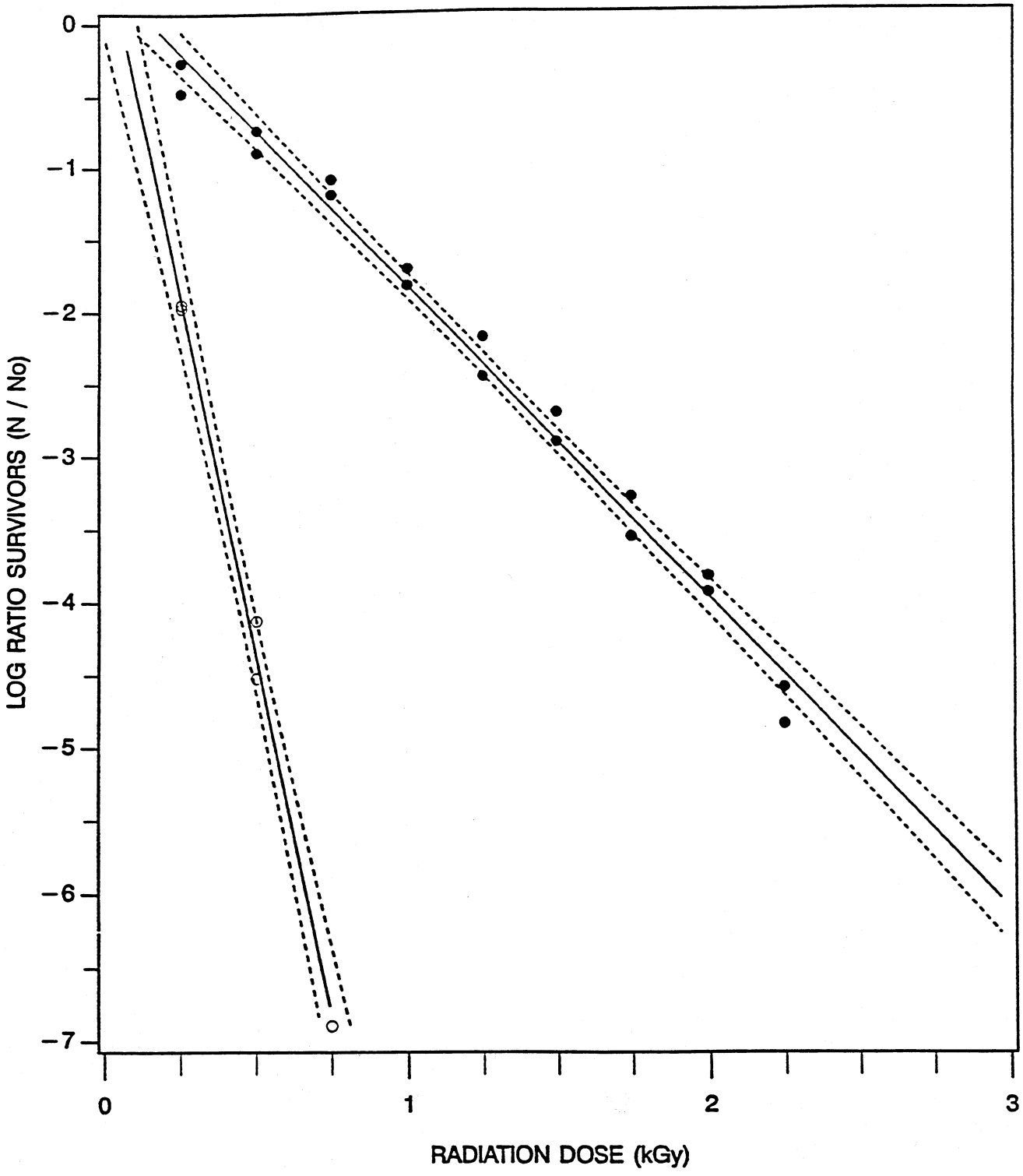

S. enteritidis
TSA
12
9
6
3
0
0
6
12
24
72
120
168
216
Time (h)
0 kGy (20 C)
0 kGy (10 C)
0 kGy (5 C)
1.25 kGy (20 C)
1.25 kGy (10 C)
1.25 kGy (5 C)
2.50 kGy (20 C)
2.50 kGy (10 C)
2.50 kGy (5 C)

SURVIVAL OF *S. typhimurium* ON IRRADIATED CHICKEN MEAT
WITH AND WITHOUT A HEAT TREATMENT FOR 120 SEC AT 60 C AFTER SIX WEEKS REFRIGERATION




1
0
-1
-2
-3
-4
-5
-6
-7
LOG RATIO SURVIVORS (N/NO)
0
.4
.9
1.4
1.9
RADIATION DOSE IN KGY
: irradiated
: heated / irradiated
: irradiated / heated

SURVIVAL OF FOUR STRAINS OF Staphylococcus aureus
IN PEPTONE (CIRCLES) OR ON MECHANICALLY DEBONED CHICKEN MEAT (DOTS)



SURVIVAL OF Staphylococcus aureus ON MECHANICALLY DEBONED CHICKEN MEAT
STATIONARY PHASE CELLS = DOT; LOG PHASE CELLS = CIRCLE

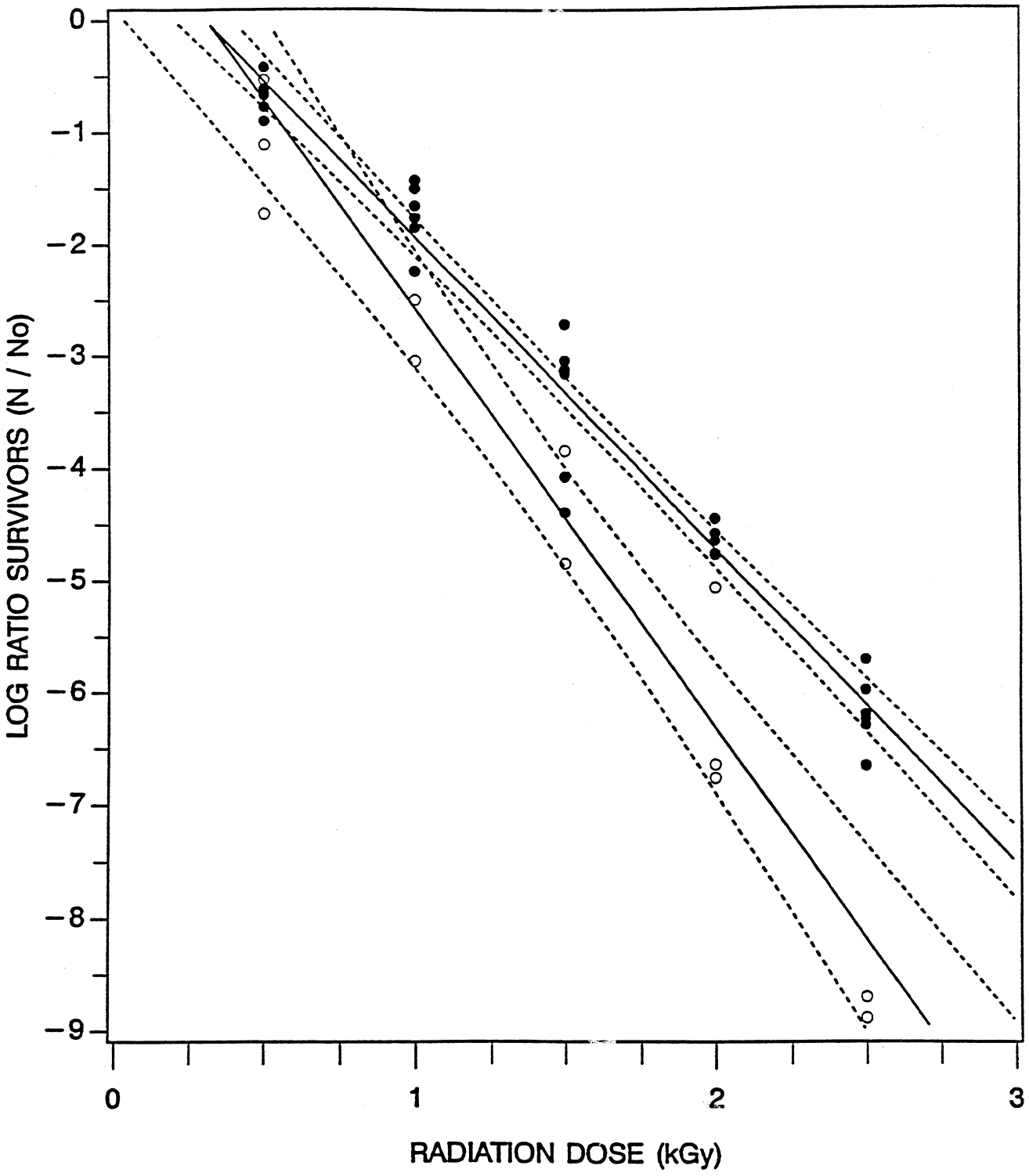


Table 1. Logarithm of average colony forming units of S. aureus ATCC 13565 surviving treatment with gamma radiation in mechanically deboned chicken meat.

Irradiation Temperature °C	Gamma radiation dose (kGy)				
	0	0.75	1.50	2.25	3.00
	---------- Log_{10} cfu ----------				
-20	9.30		7.38		3.15
-10		8.13		4.97	
0	9.23		5.49		0
+10		8.13		3.96	
+20	9.25		5.81		0.86

REF: Thayer, D. W. and G. Boyd 1992 J. Food Sci. 57:848-851

Table 2. Challenge study with S. aureus ATCC 13565 in mechanically deboned chicken meat

Hours abuse at 35°C		Radiation Dose (kGy) 0	0.75	1.50	2.25	3.0
0	cfu[a]	3.86	0.79	ND	ND	ND
	toxin	negative	negative	negative	negative	negative
20	cfu	7.48	5.78	ND	ND	ND
	toxin	positive	negative	negative	negative	negative

[a] $\log_{10}$cfu/g of mechanically deboned chicken meat

ND = not determined; neg = negative; pos = positive