EXPOSURE ASSESSMENT OF *SALMONELLA* SPP. IN EGG PRODUCTS

Introduction

About one-third of all eggs produced in the U.S. are marketed as egg products (i.e., whites, yolks, or whole eggs). These eggs are sent to processing plants where they are cracked open. The internal contents of these eggs are accumulated in large vats and subsequently pasteurized. Depending on the manufacturer's needs, yolk and white material may be separated just after each egg is cracked open. These liquids are then shunted to separate holding vats. Alternatively, the entire contents of the egg may be directed to a holding vat.

In the 1960s, egg products were thought to be responsible for many human cases of *Salmonella* illness. Egg products were often sold in bulk as powdered or liquid product and were used in the commercial preparation of foods. It was discovered that an unacceptable number of these products were contaminated with *Salmonella*. Because of this discovery, USDA in 1970 developed regulations that required the pasteurization of all egg products. Since passage of those regulations, egg products have not been identified as a source of *Salmonella* illness in humans.

The current regulations are being reevaluated within this risk analysis effort. USDA periodically samples pasteurized egg products and has occasionally found evidence of *Salmonella* contamination in these samples. Such results suggest that current pasteurization practice has not been completely effective at eliminating *Salmonella* from all egg products. USDA is converting its current process standards into performance standards. Current pasteurization regulations specify times and temperatures for treating egg products. These regulations are called process standards because they dictate the process manufacturers must follow. The outcomes from following this process are highly variable from plant to plant or even from vat to vat. For example, a heavily contaminated vat is subjected to the same heat for the same period during pasteurization as a vat that contains few *Salmonella*. The outcome of pasteurizing these two vats may differ because *Salmonella* may survive the pasteurization treatment of the heavily contaminated vat, but pasteurization would probably eliminate any *Salmonella* in a vat containing just a few cells.

To avoid these types of discrepancies in pasteurized egg product outcomes, process standards will be replaced with performance standards. These performance standards will specify the required outcome from pasteurization, but they will not specify the process to achieve this outcome. Performance standards provide for a more flexible approach. Manufacturers can adjust the process they use to suit their specific circumstances, but they must still demonstrate that they comply with the standards.

This exposure assessment determines the frequency with which people are exposed to different doses of *Salmonella* spp. in servings of foods prepared from seven categories of pasteurized egg products. The basic egg product categories are whole egg, white, and yolk. Whole egg product results from breaking shell eggs and collecting their entire contents. White and yolk egg products result from breaking shell eggs but separately collecting the white and yolk. Manufacturers of egg products may also blend whole egg and yolk with salt or sugar. Therefore, four additional categories result: whole egg with salt, whole egg with sugar, yolk with salt, and yolk with sugar (Table 3-29).

TABLE 3-29 MODELED CATEGORIES OF EGG PRODUCTS.

Whole Egg Products			**Yolk Products**			**White Products**
Whole egg	Whole egg with salt	Whole egg with salt	Egg yolks	Egg yolks with salt	Egg yolks with sugar	Egg whites

Overview of the Egg Products Exposure Assessment Model

> **Servings of Egg Products**
> Just as eggs may be consumed by themselves or as ingredients in many types of recipes, egg products may be consumed in various types of products. A serving of egg product could be included in a serving of scrambled eggs, a waffle, a slice of cake, or a serving of egg nog. Sizes of servings would be expected to vary from just a few grams to hundreds of grams.

Egg products are considered in that part of the food chain from just before pasteurization to consumption of servings prepared from egg products. Figure 3-38 shows the most important components of this process. Pasteurization has special prominence in this assessment because it is the principal risk management measure being evaluated by this risk assessment. The amount of *Salmonella* in a serving of egg products depends on the amount present just prior to pasteurization, the amount of *Salmonella* destroyed during pasteurization, the amount of growth that occurs during storage after pasteurization, the amount of additional destruction of bacteria that occurs during cooking, and the size of the serving. These steps comprise the exposure assessment for egg products and provide an estimate of the number of bacteria to which a consumer is exposed in a single serving of food made with egg products. When a contaminated serving is consumed, the dose-response relationship described in chapter 4 estimates the probability that illness will result. The results of combining the exposure assessment with dose-response relationship are described in chapter 5.

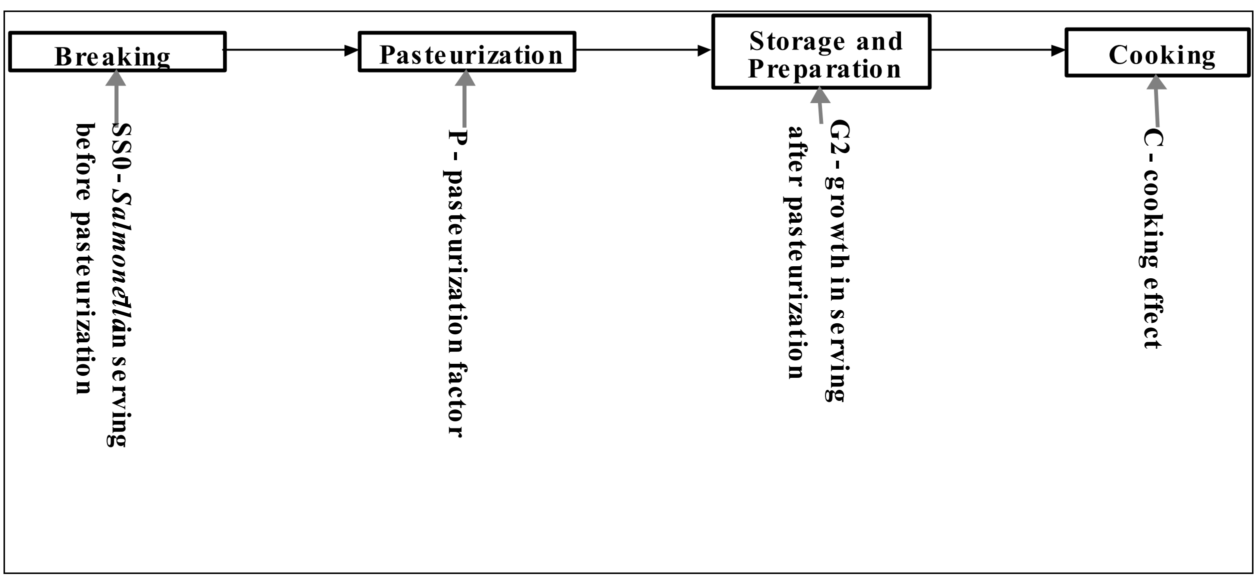

FIGURE 3-38 FLOW OF EGG PRODUCTS IN EXPOSURE ASSESSMENT.

This exposure assessment for egg products includes all *Salmonella*, whereas the shell eggs exposure assessment discussed above considers only SE. In contrast to the problem with SE in shell eggs, the origins of *Salmonella* within egg products are less well understood. Manufacturing egg products begins with the cracking of shell eggs to accumulate large volumes of liquid white or liquid yolk, or liquid whole egg. At some point in the manufacture of egg products, *Salmonella* contamination occurs. This contamination is not limited to SE, and it is likely that sources of *Salmonella* besides the internal contents of the egg are partly responsible. Alternative sources of bacteria include the shells of eggs and the breaking equipment.

This exposure assessment for egg products begins at the breaker plant rather than on the farm. *Salmonella* that are not SE account for a substantial portion of the contamination of egg products. Although the source of this contamination may be on the farm, there is no direct evidence describing the relationship between *Salmonella* spp. on the farm and *Salmonella* spp. in egg products just before pasteurization. Consequently, this exposure assessment begins just before pasteurization, accepting the fact of contamination without developing the details of its causes.

At the processing plant, or breaking plant, eggs are cracked and the liquid is accumulated from thousands of eggs. The vats, or bulk tanks, containing pre-pasteurized yolk, white, or whole egg product constitute the basic product types. Ingredients such as sugar or salt may be added to these vats. Contamination levels vary among different product types and among vats of the same product type. The amount of *Salmonella* contamination in a vat is the critical variable of interest at this stage of the exposure assessment.

Currently, during pasteurization, egg products are subjected to target temperatures for specific amounts of time. These target temperatures differ for the seven product categories. Heat destroys bacterial cells, but it must not cook the egg material to the point at which its usefulness as a foodstuff is affected. Different combinations of pasteurization time and temperature result in different levels of effectiveness in destroying *Salmonella*. If pasteurization is effective, then the probability that *Salmonella* will survive this process is low. If pasteurization is ineffective, then *Salmonella* can survive the process and grow in numbers, and consumers may eventually become exposed.

After pasteurization, the processor, wholesaler, retailer, and consumer may store egg products. Surviving *Salmonella* may grow in the egg products during these times. The amount of growth depends on the combination of storage times and temperatures.

Meals prepared using egg products may be cooked. Like pasteurization, cooking can destroy *Salmonella*. Like pasteurization, its effect is variable. Cooking effectiveness depends on the cooking method, the cooking temperature, and the duration of cooking. Individual cooking behavior is highly variable. It depends on many factors; one of these is the food cooked. Scrambled eggs and birthday cakes prepared from egg products, for example, are typically subjected to very different temperatures for very different times.

The purposes of this exposure assessment are to estimate the baseline exposure of consumers to *Salmonella* in egg products and evaluate the log reduction from pasteurization in reducing these exposures. Data and models were developed to investigate different levels of pasteurization effectiveness that can influence human exposure to *Salmonella*s and subsequent illness.

Mathematical summary of the egg products exposure assessment

The model used to estimate the numbers of *Salmonella* in egg products consumed begins with the number of *Salmonella* in a serving before pasteurization. This depends on the size of the serving and the category of egg product. The serving is pasteurized and the number of *Salmonella* remaining in the serving has to be estimated (Equation 3.19). Pasteurization's effectiveness also depends on the category of egg product.

The model next estimates the amount of growth that occurs in the serving after pasteurization. Then it estimates the effectiveness of cooking in destroying the bacteria that survived and grew after pasteurization. These steps determine the number, or dose, of *Salmonella* consumed in the serving (Equation 3.20 below).

Illness is not necessarily the outcome from consuming *Salmonella* in a serving of egg product. The probability that illness occurs for a given dose in a serving is estimated using the dose-response relationship developed in chapter 4 (Equation 3.21 below). Each of these relationships is developed below.

<u>Bacteria after pasteurization</u>

The number of *Salmonella* in a serving after pasteurization depends on the number of *Salmonella* per serving just before pasteurization and the effect of pasteurization on reducing *Salmonella* numbers within contaminated eggs.

$$SS_1 = SS_0 \text{ x } P \qquad (3.19)$$

where

SS_1 = the number of *Salmonella* in a serving after pasteurization
SS_0 = the number of *Salmonella* in a serving before pasteurization. This number can range from zero cells to thousands of cells.
P = the fraction of *Salmonella* cells that survive pasteurization.

> **Example**
> S_0 = 12 *Salmonella* in a particular serving. This is determined by both the concentration of *Salmonella* per ml and the serving size, which can vary from just a few grams to hundreds of grams.
> P = 1.2 log reduction due to pasteurization (a multiplier of $10^{-1.2}$ = 0.063)
> S_1 = 12 x 0.063 = 0.76, which is the expected number of *Salmonella* in a serving after pasteurization. This is input into a Poisson distribution to determine the modeled bacteria in the serving.

The range in the number of *Salmonella* before pasteurization differs by egg product category and serving size. Just as the shell egg exposure assessment follows an egg through the system, this assessment follows an individual serving. Because of the mixing of large numbers of eggs together, the consumption unit of interest in egg products is the serving, which by definition would expose only one person. For each serving, the number of *Salmonella* is randomly selected from a probability distribution that reflects the natural variability in the number of bacteria found in a serving of a certain size from a certain egg product category. Equation 3.19 shows that the number of bacteria in a serving of egg product before pasteurization is reduced by the effect of pasteurization. The fraction, *P*, ranges over the [0,1] interval. Zero 0 is complete elimination of the bacteria and one is complete survival. Values of *P* are entered into this equation as point estimates because they represent a decision variable. That is, risk managers would be responsible for establishing a desired kill rate, which effectively establishes a deterministic value for *P*. The input distributions for SS_0 and the point estimates for *P* are described in their own sections below. By repeatedly considering different servings from contaminated vats, the output of Equation 3.19 is a distribution of values that capture the variability attending the estimate of this post pasteurization value, SS_1.

Bacteria after growth and cooking

The number of *Salmonella* per serving after cooking depends on the number of *Salmonella* after pasteurization (SS_1 above), the growth of these bacteria after pasteurization, and the attenuating effect of cooking.

$$SS_2 = SS_1 \text{ x } G_2 \text{ x } C \quad (3.20)$$

where SS_1 is defined above and G_2 = the relative growth of *Salmonella* from the time of pasteurization to the time of preparation and cooking and C = the fraction of cells that survive cooking.

Inputs G_2 and C are the result of complex interactions of time and temperature. These inputs are further explained in their own sections below. The value of G_2 generally ranges over the $[1,10^{10}]$ interval. One means no growth occurred, and 10^{10} means one organism grew to 10 billion organisms at the time the serving was prepared. G_2 enters the equation as a random value selected from a distribution based on this interval. The fraction, C, ranges over the [0,1] interval, where 0 is complete elimination of the bacteria and 1 is complete survival. C enters this equation as a random value selected from a distribution.

The equation begins with the *Salmonella* in a serving that survive pasteurization and allows them to grow until the egg meal is cooked. This number of bacteria is then reduced by the effect of cooking to produce the number of bacteria in the serving that are consumed. By repeatedly calculating SS_2 values for different egg product servings, the output of Equation 3.20 is a distribution of values that capture the variability attending the estimate of the number of *Salmonella* per serving of egg product.

Example

S_1 = 1 *Salmonella* bacterium
G_2 = 0.1 $\log_{10}$ of growth (a multiplier of $10^{0.1}$ = 1.26)
C = 12 log reduction due to cooking (a multiplier of 10^{-12})
S_2 = 1 x 1.26 x 10^{-12} = 1.26 x 10^{-12}, which is the expected number of *Salmonella* per serving.

Probability of illness per serving

The probability of illness per serving is calculated using a dose-response function with the number of *Salmonella* per serving as its argument.

$$I_S = DR(SS_2) \quad (3.21)$$

where I_S = the probability of illness resulting from consuming a serving of egg product. SS_2 is as defined above.

Given a particular dose (i.e., number of bacteria per serving), this equation calculates the probability that each serving might cause illness. If all possible servings of egg product are considered, the mean of the resultant distribution of probabilities can be calculated. This value can be interpreted as the expected probability that a member of the general population of egg product eaters will get ill from any given serving. Alternatively, when multiplied by the number of servings eaten in a year it

Example

S_2 = 1.26 x 10^{-12} expected *Salmonella*
DR(222) = 3.1 x 10^{-15} likelihood of illness given that average expected dose. Thus, the likelihood of illness would be extremely remote in this example.

yields the expected number of illnesses in a year. Taken alone and interpreted somewhat differently, the expected probability of an illness is the expected number of illnesses that result per serving of egg product consumed in the U.S. This latter value is one of the final measurements of this risk assessment and is presented in chapter 5.

The following sections of this chapter describe how the inputs SS_0, P, G, and C were modeled. These elemental components of the conceptual model are combined to estimate a distribution of *Salmonella* per serving. This distribution is combined with the dose-response function to assess the risk of illness from *Salmonella* in egg products in the Risk Characterization chapter. The exposure assessment model is programmed in Visual Basic for Applications. Inputs and outputs are stored in Excel spreadsheets.

Number of *Salmonella* in a serving before pasteurization, SS_0

The number of *Salmonella* in a serving before pasteurization depends on the type of egg product serving, the concentration of *Salmonella* in the vat that produced the serving, and the size of the serving. High densities of *Salmonella* per gram in vats will result in high densities of *Salmonella* per gram of serving. Larger servings will, on average, contain more *Salmonella* than smaller servings. Contamination levels in vats of white, whole egg, and yolk are different. The servings from these vats will contain different numbers of *Salmonella*. To estimate the number of *Salmonella* in a serving of egg product, the algorithm in Table 3-30 was used. For a given egg product type, the number of *Salmonella* per gram in the egg product vat is estimated. With the number of grams in the serving, the number of *Salmonella* in the dose was determined.

TABLE 3-30 DETERMINING THE INITIAL LEVEL OF *SALMONELLA* IN A SERVING OF EGG PRODUCT.

Input	Description	Estimation
i	Index for type of egg product serving	See Figure 3-39
W_i	*Salmonella* per gram in vat of egg product type *i*	White; Weibull(0.301, 9.03) Whole egg, whole egg 10% salt, and whole egg 10% sugar; Weibull (2.87, 11.8) Yolk, yolk 10% salt, and yolk 10% sugar; Weibull (0.236, 8.43)
R	Size of serving in grams	Empiric distribution derived from CSFII.
SS_0	Number of *Salmonella* in a serving before pasteurization	$Poisson(W_i \times R)$

Figure 3-39 shows the relative frequency of the seven categories of egg products based on total weight of production. These relative frequencies of product types are estimated from data from the National Agricultural Statistics Service,[13] but those data only provide the proportion of egg products for whole egg, white, and yolk, and the amount of blended whole egg and yolk with salt or sugar. They do not break the blended product out by salt or sugar content. Based on work done by Research Triangle Institute,[14] it is assumed that 66% of blended whole egg products are 10% salt and the remaining 34% of these are 10% sugar. Using the same report for blended yolk products, it is assumed that half are 10% salt products and half are 10% sugar products. Estimates were based on data from the National Agricultural Statistics Service[13] and assumed fractions of different egg blends.[14]

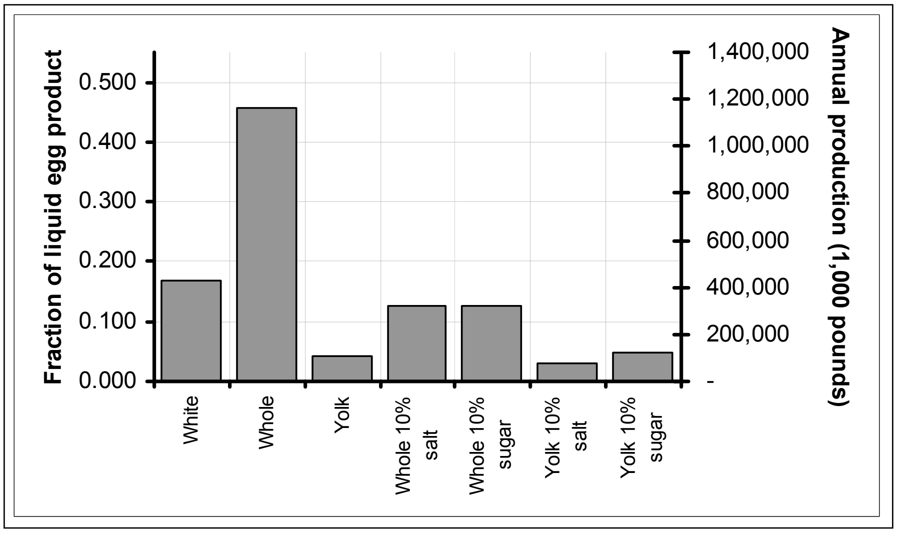

FIGURE 3-39 RELATIVE FREQUENCY AND TOTAL PRODUCTION OF VARIOUS TYPES OF LIQUID EGG PRODUCTS.

The *Salmonella* per gram in vats of white, whole, and yolk egg product is based on a transformation of a Weibull distribution as explained in Annex F. Briefly, the Weibull is expressed as

$$W(x \mid b, c) = 1 - e^{-(x/c)^b} \tag{3.22}$$

The modified Weibull (μ,σ) probability distribution has the following functional form:

$$P(W_i) = 1 - e^{-e^{\left[\frac{ln\ (W_i) - \mu}{e^{\sigma}}\right]}} \tag{3.23}$$

where $b = e^{-\sigma}$ and $c = e^{\mu}$.

Different parameter values have been estimated for each egg product type, and the resultant distributions are shown in Figure 3-40. A random selection from the relevant probability distribution multiplied by 3 (to account for possible clustering) is the concentration of *Salmonella* per gram of egg product in a vat.

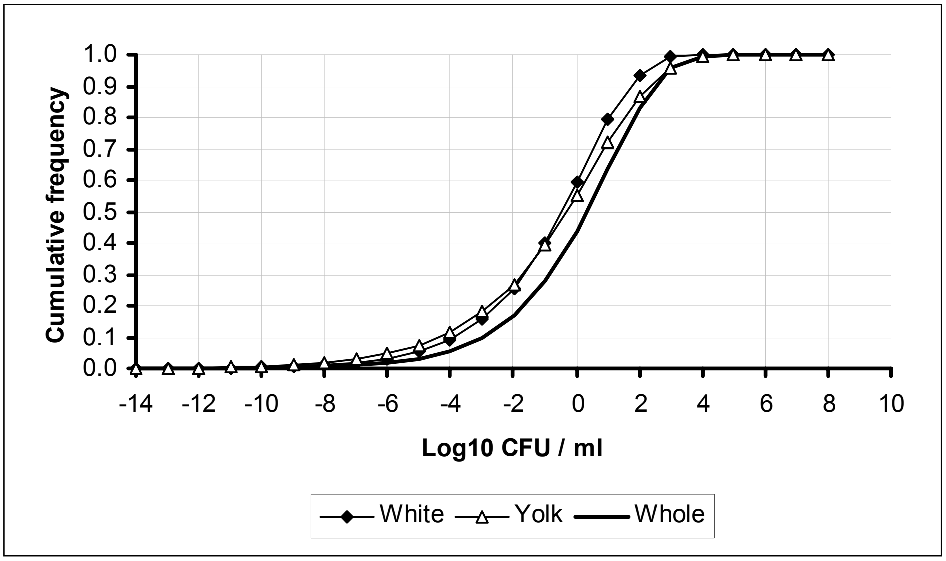

FIGURE 3-40 CUMULATIVE FREQUENCY OF LOG_{10} *SALMONELLA* PER GRAM IN VATS OF WHITE, YOLK, AND WHOLE EGG PRODUCT BEFORE PASTEURIZATION.

The number of grams of egg product consumed in a serving is based on an analysis of the CSFII database, as explained in Annex H. Table 3-31 summarizes the frequencies of three types of consumed products: main meals, beverages, and ingredients. It gives percentiles for the number of grams consumed for each. Egg products may be consumed as the main meal, for example, in servings of scrambled eggs or omelets. The amount of egg product actually consumed (i.e., the serving size) varies among individuals. This variability is shown by the distribution in Table 3-31. Figure 3-41 is a graphical representation of serving sizes.

Egg products may also be consumed in beverages such as eggnog. These serving sizes tend to be large. The vast majority of egg products are used as ingredients in other foods such as pasta, bread, and cake. When used as ingredients, the serving sizes of egg products can be small. For example, there is only a fraction of egg product, on a per-weight basis, in a piece of commercially prepared bread.

For this analysis, it is assumed that serving size is not correlated with type of egg product. This is a simplifying assumption that may not adequately reflect reality. For instance, the amount of product in servings made with whole egg product may be larger than servings made with yolk product. Because whole egg product has a different distribution of *Salmonella* concentration than yolk egg product, this could affect the risk of human illness.

The number of *Salmonella* in a serving is estimated using the serving size and the concentration of *Salmonella* per gram in a vat. The contamination of servings from a vat is assumed to follow a Poisson process. The average of the Poisson distribution is the average number of organisms per serving of fixed size from a particular vat. The SS_0 in a single serving is randomly sampled from this Poisson distribution. By repeatedly sampling from the probability distributions used to estimate SS_0 and using the algorithm in Table 3-1, a distribution of SS_1 values can be generated. This captures the variability attending the number of *Salmonella* in a serving of egg product.

TABLE 3-31 SUMMARY OF CONSUMPTION INFORMATION FOR SERVINGS MADE FROM EGG PRODUCTS.

		All Egg Products			**Potentially Undercooked Egg Products**		
	Meal type	*Main Meal*	*Beverage*	*Ingredient*	*Main Meal*	*Beverage*	*Ingredient*
	Consumption average (g/p/d)	77.8	182.5	36.0	79.1	182.5	13.6
	Std Dev (g)	49.0	75.1	71.0	48.9	75.1	21.6
	Eating occasions	32,345,212	286,428	226,268,156	28,304,347	286,428	28,312,529
	Fraction	0.125	0.001	0.874	0.109	0.001	0.109
	n =	2,594	17	16,666	2,291	17	2,042
Percentile	5.0%	24	71	1	24	71	2
	10.0%	34	95	1	38	95	3
	20.0%	41	127	3	42	127	4
	30.0%	45	127	5	45	127	5
	40.0%	57	127	6	60	127	7
	50.0%	76	191	9	77	191	8
	60.0%	80	191	13	82	191	10
	70.0%	86	254	22	86	254	12
	80.0%	94	254	46	94	254	16
	90.0%	138	254	105	138	254	25
	95.0%	173	286	164	170	286	40
	97.0%	188	286	239	175	286	55
	98.0%	221	286	293	220	286	76
	99.0%	281	286	320	293	286	111
	99.1%	293	286	334	293	286	111
	99.2%	293	382	344	300	382	132
	99.3%	300	382	377	302	382	133
	99.4%	312	382	402	315	382	167
	99.5%	315	382	435	324	382	167
	99.6%	324	382	477	342	382	188
	99.7%	350	382	516	350	382	202
	99.8%	350	382	557	350	382	209
	99.9%	350	382	639	350	382	221
	100.0%	410	382	959	410	382	304

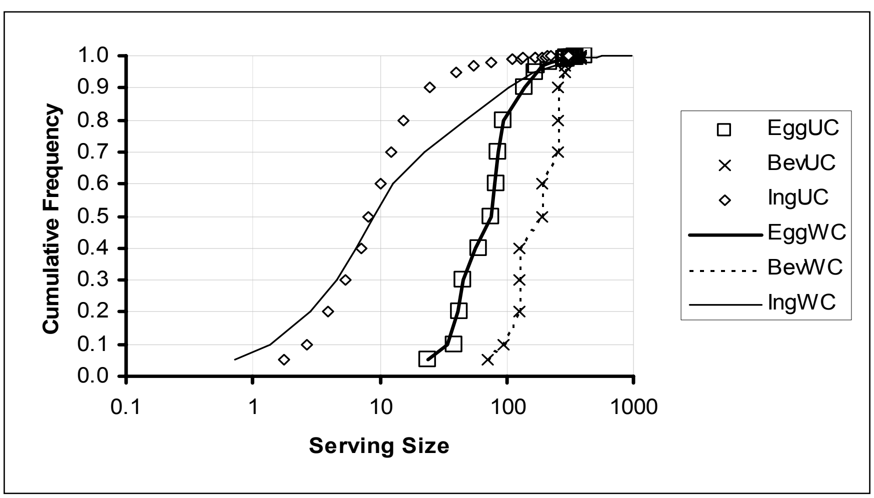

FIGURE 3-41 CUMULATIVE FREQUENCY OF SERVING SIZES BY TYPE OF SERVING CONSUMED.

<u>Pasteurization effectiveness, *P*</u>

P is the fraction of *Salmonella* that survives a pasteurization treatment. It is a regulatory variable in this analysis, and the model user can set its value. Different levels of pasteurization effectiveness are modeled to determine the resulting effect on exposures to *Salmonella* and their concomitant risks of human illness or death. In this manner, the relationship between *P* and risk of illness or death can be described in support of the determination of regulatory standards.

Annex G derives five different functions for the effect of pasteurization in the seven different products modeled. The functional relationships for these pasteurization effects are summarized in Table 3-32, Table 3-33, Table 3-34, Table 3-35, and Table 3-36. These tables present the equations used to estimate pasteurization effectiveness. The inputs required for these equations are presented as well. More details on these relationships are provided in Annex G.

TABLE 3-32 DETERMINATION OF LOG_{10} REDUCTION IN LIQUID WHOLE EGG WITH 10% ADDED SALT AND LIQUID YOLK WITH 10% ADDED SALT.

Input	Description	Value
T	Pasteurization temperature	62.2
T	Pasteurization time	7.0
a	Parameter	4.810836
B	Parameter	3.263478
C	Parameter	–0.539650
D	Parameter	0.231221
E	Parameter	0.655073
F	Parameter	0.701920
G	Parameter	0.101009
δ (whole egg)	Parameter	1
δ (yolk)	Parameter	–1
Log_{10} reduction	Calculation	$-\log_{10}(1 + \exp(b + c\delta + d(T-60)) \times \ln(t) + a + e\delta + f(T-60) + g(T-60)^2)$

TABLE 3-33 DETERMINATION OF LOG_{10} REDUCTION IN LIQUID WHOLE EGG WITH 10% ADDED SUGAR.

Input	Description	Value
T	Pasteurization temperature	62.2
T	Pasteurization time	7.0
D	Parameter	–3.394085
E	Parameter	0.655432
W	Calculation	$\exp\left(d + e\left(T - 55\right)\right)$
A	Calculation	$\frac{w}{\log_{10}\left(e\right)}$
X	Parameter	0.331788
Y	Parameter	–0.070704
Z	Parameter	0.007454
B	Calculation	$\exp\left(x + y\left(T - 55\right) + z\left(T - 55\right)^2\right)$
ln(*p*(*t*))	Calculation	$-at^b$
Log_{10} reduction	Calculation	$\log_{10}(e^{\ln(p(t))})$

TABLE 3-34 DETERMINATION OF LOG_{10} REDUCTION IN LIQUID YOLK WITH 10% ADDED SUGAR.

Input	Description	Value
T	Pasteurization temperature	61.1
T	Pasteurization time	7.0
E	Parameter	11.65200
F	Parameter	–0.28275
A	Calculation	$e+f\left(T-55\right)$
G	Parameter	–46.69955
H	Parameter	9.28490
K	Parameter	–0.29105
B	Calculation	$g+h\left(T-55\right)+k\left(T-55\right)^{2}$
Log_{10} reduction	Calculation	$-\log_{10}\left(1+\exp\left(a\ln\left(t\right)+b\right)\right)$

TABLE 3-35 DETERMINATION OF LOG_{10} REDUCTION IN PLAIN LIQUID WHOLE EGG AND YOLK.

Input	Description	Value
T (whole egg)	Pasteurization temperature	60
T (yolk)	Pasteurization temperature	61.1
T	Pasteurization time	7.0
A	Parameter	3.8258
D (whole egg)	D-value	$12.1199-0.20834T$
D (yolk)	D-value	$8.1518-0.1382T$
b	Calculation	$b=\ln\left(\frac{10^{3}-1}{(3D)^{a}}\right)$
Ln(*k*)	Calculation	$a+b\left(T-50\right)+c\left(pH-7\right)+d\left(T-50\right)\times\left(pH-7\right)$
Log_{10} reduction	Calculation	$-\log_{10}\left(1+\exp\left(a\ln\left(t\right)+b\right)\right)$

TABLE 3-36 DETERMINATION OF LOG_{10} REDUCTION IN LIQUID EGG WHITE.

Input	Description	Value
T	Pasteurization temperature	56.67
t	Pasteurization time	7.0
pH	pH of product	8.8
a	Parameter	
b	Parameter	
c	Parameter	
d	Parameter	
ln(*k*)	Calculation	$a+b(T-50)+c(pH-7)+d(T-50)\times(pH-7)$
k	Calculation	$e^{\ln(k)}$
e	Parameter	
f	Parameter	0
g	Parameter	
h	Parameter	–1.69467
i	Parameter	0
j	Parameter	0
ln(*w*)	Calculation	$e+f(T-50)+g(pH-7)+h(T-50)\times(pH-7)+i(1$
w	Calculation	$e^{\ln(w)}$
ln(*p*(*t*))	Calculation	$-kt+\ln\left(1+\frac{k}{w}\times\left(1-e^{-wt}\right)\right)$
Log_{10} reduction	Calculation	$\log_{10}(e^{\ln(p(t))})$

Current FSIS standards require that various egg product types be heated to a specific temperature for a requisite time. Table 3-37 shows the $\log_{10}$ reduction for the current process standards. These values were derived by solving the equations in the preceding tables for the time and temperature requirements for each egg product type. These are used as default values for *P* in this exposure assessment, where $P = 10^{\text{LogReduction}}$.

TABLE 3-37 REQUIREMENTS AND EXPECTED LOG_{10} REDUCTIONS FOR MODELED TYPES OF EGG PRODUCTS.

	Requirement		
Product	**Time**	**Temp**	**Log_{10} Reduction**
White	3.5	56.67	–3.3
Whole	3.5	60	–5.9
Yolk	3.5	61.11	–5.5
Whole 10% salt	3.5	62.22	–6.0
Whole 10% sugar	3.5	62.22	–42.0
Yolk 10% salt	3.5	63.33	–7.2
Yolk 10% sugar	3.5	63.33	–12.4

Growth effect after pasteurization, G_2

Egg products are stored after pasteurization for varying times and temperatures. These products must be transported from the processor to wholesale or retail outlets and then transported to homes or commercial facilities. Depending on the places of storage, the products may at various times be frozen, refrigerated, or held at room temperature. Because of a lack of data specific to growth of *Salmonella* in egg products, this growth is assumed similar to growth of SE in shell eggs. Egg products are homogenized. For whole egg products, this means the yolk and white are mixed; therefore, the concept of YMB does not apply to *Salmonella* in whole egg products. Nor does it apply to the separated products. It is assumed that *Salmonella* in whole egg products and yolk egg products grows as if it were SE in a shell egg after YMB has occurred. *Salmonella* in egg white products is assumed to grow at rates predicted for SE in albumen in the shell egg exposure assessment. Shell eggs initially contaminated in the white can occasionally support a low rate of growth, but the growth rate increases substantially when YMB occurs. In the absence of yolk material, growth rates in white egg products are low throughout the post-pasteurization period. *Salmonella* growth in white and yolk is described in the shell egg exposure assessment presented earlier in this chapter. Additional details can be found in Annex E. The same approach is used here for estimating growth in egg products.

Modeled Pasteurization Times Are Higher Than Required Times

Pasteurization times for eggs products are modeled at 7 minutes. This assures that every particle is subjected to 3.5 minutes at the required temperature under laminar flow conditions.

Because growth of *Salmonella* in egg products depends on the time and temperature of storage of the egg product, estimates of these values are needed. Absent better data for these time and temperature relationships for egg products, distributions for storage times and temperatures were estimated in expert elicitations conducted by RTI[15] specifically for egg products. Variability in storage times and temperatures for egg products is characterized using Pert distributions with the parameters shown in Table 3-38. A distinction is made between egg products stored at room temperature and egg products stored in the refrigerator. Most egg products are stored continuously in refrigerators.[15] A small proportion of egg products may be stored for a short time at room temperature. Table 3-38 presents distribution parameters for egg white products, Table 3-39 provides this information for whole egg products, and Table 3-40 gives it for yolk products.

For a given egg product category, a random value from the appropriate time and temperature distribution is selected and feeds into the growth equations to predict the value of G_2 for a serving. By repeatedly considering different times and temperatures, the output of the growth equations is a distribution of values that capture the variability attending the estimate of G_2. This distribution is used in Equation 3.2 to estimate the number of *Salmonella* consumed in a serving. The effect of cooking is also included in Equation 3.2 and is discussed in the next section.

TABLE 3-38 PARAMETERS FOR PERT DISTRIBUTIONS FOR STORAGE INPUTS FOR EGG WHITE PRODUCTS.

Input	Model Abbreviation	Min	Mid	Max
Days product is stored in the refrigerator	RefriDays	2.00	10.00	22.00
Refrigerator temperature	RefriTemp	0.00°C	3.33°C	4.44°C
Fraction of product stored at room temperature	FractRS	0.02	0.05	0.10
Days product is stored at room temperature	RSDays	0.02	0.04	0.17
Room temperature	RSTemp	15.56°C	21.11°C	26.67°C

TABLE 3-39 PARAMETERS FOR PERT DISTRIBUTIONS FOR STORAGE INPUTS FOR WHOLE EGG PRODUCTS.

Input	Model Abbreviation	Min	Mid	Max
Days product is stored in the refrigerator	RefriDays	2.00	5.50	13.00
Refrigerator temperature	RefriTemp	0.00°C	3.33°C	4.44°C
Fraction of product stored at room temperature	FractRS	0.02	0.05	0.10
Days product is stored at room temperature	RSDays	0.02	0.04	0.17
Room temperature	RSTemp	15.56°C	21.11°C	26.67°C

TABLE 3-40 PARAMETERS FOR PERT DISTRIBUTIONS FOR STORAGE INPUTS FOR EGG YOLK PRODUCTS.

Input	Model Abbreviation	Min	Mid	Max
Days product is stored in the refrigerator	RefriDays	2.00	5.50	11.00
Refrigerator temperature	RefriTemp	0.00°C	2.22°C	4.44°C
Fraction of product stored at room temperature	FractRS	0.02	0.05	0.10
Days product is stored at room temperature	RSDays	0.02	0.04	0.17
Room temperature	RSTemp	15.56°C	21.11°C	26.67°C

Attenuation from cooking, *C*

The effectiveness of cooking in destroying *Salmonella* depends only on the type of serving in this model. It is not correlated with the category of egg product. This is a simplifying assumption that may bias the estimated risk per serving if bacteria in certain egg product categories are more thoroughly or less thoroughly destroyed than in other categories.

Values for *C* for four different $\log_{10}$ reductions, shown in Table 3-41, are based on estimates for cooking shell eggs. These estimates are from the 1998 SE risk assessment for shell eggs and egg products.[10] All egg products served as a main meal are assumed to be either scrambled or served as omelets. Consumption data support the assumption that soft boiled, poached, over-easy eggs, and so on would be made with shell eggs. The exposure assessment for shell eggs used a $\log_{10}$ reduction of 4.9 for half the eggs that are scrambled or made into omelets and 6.1 for the other half. The 1998 SE risk assessment also estimated that about 1.7% of shell eggs consumed as ingredients are consumed raw.[10] A similar percentage for egg products consumed as part of a main meal is assumed here. This is reasonable considering that egg products are considered a ready-to-eat item. Thus, 2% of egg products served as a main meal will not be cooked, 49% will have a $\log_{10}$ reduction of 4.9, and 49% will have a $\log_{10}$ reduction of 6.1. The same $\log_{10}$ reductions are applied to potentially undercooked egg products served as ingredients. All egg products served in beverages are served raw, and thus have a 0-$\log_{10}$ reduction. It is further assumed that all egg products served as ingredients in mixtures that are well cooked would have a 12-$\log_{10}$ reduction. These estimates are consistent with those presented for shell eggs in Table 3-26.

The proportion of egg product servings by different meal types is given earlier in Table 3-31. By repeatedly sampling different meal types and $\log_{10}$ reductions from cooking those meal types, as shown in Table 3-31, a distribution of values that captures the variability attending the estimate of *C* is derived; where $C = 10^{-\text{LogReduction}}$. This distribution, a discrete distribution limited to the values shown, is used in Equation 3.2 to estimate the number of *Salmonella* consumed in a serving.

TABLE 3-41 FRACTIONS, *C*, FOR DIFFERENT TYPES OF COOKING AND ASSOCIATED LOG_{10} REDUCTIONS.

Meal type		Fractions for Possible Log_{10} Reductions 0	4.9	6.1	12
Potentially undercooked egg products	Main meal	0.02	0.49	0.49	0.00
	Beverage	1.00	0.00	0.00	0.00
	Ingredient	0.02	0.49	0.49	0.00
Well-cooked egg products	Main meal	0.02	0.49	0.49	0.00
	Ingredient	0.00	0.00	0.00	1.00

Exposure Assessment Results: *Salmonella* spp. in Egg Products

The model was run with 100,000 iterations for each of the seven egg products. This is equivalent to 700,000 servings of egg product foods. Results are reported for the elements of the conceptual model, reproduced below as Figure 3-42.

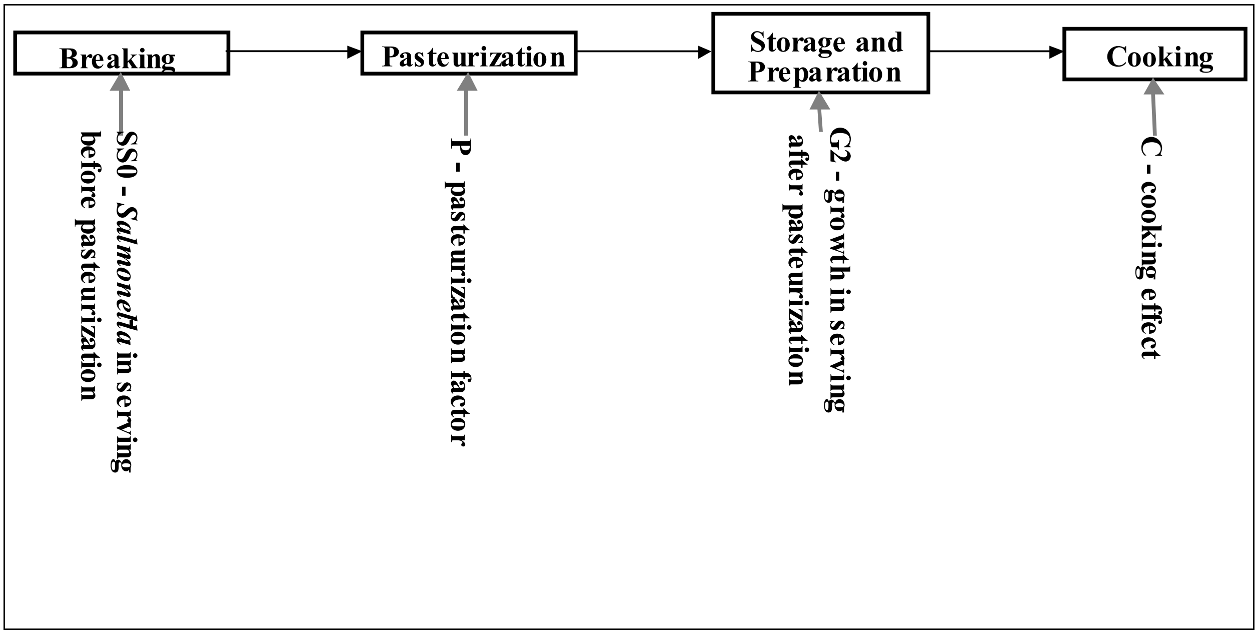

FIGURE 3-42 FLOW OF EGG PRODUCTS IN RISK ASSESSMENT.

***Number of* Salmonella *in a serving before pasteurization,* SS_0**

Figure 3-43 presents the distribution of the number of *Salmonella* in servings before pasteurization, SS_0. The number is reflective of the concentration per gram shown in Figure 3-40 but also takes into account the variability in serving sizes. Thus, larger serving sizes result in exposure to more bacteria, on average.

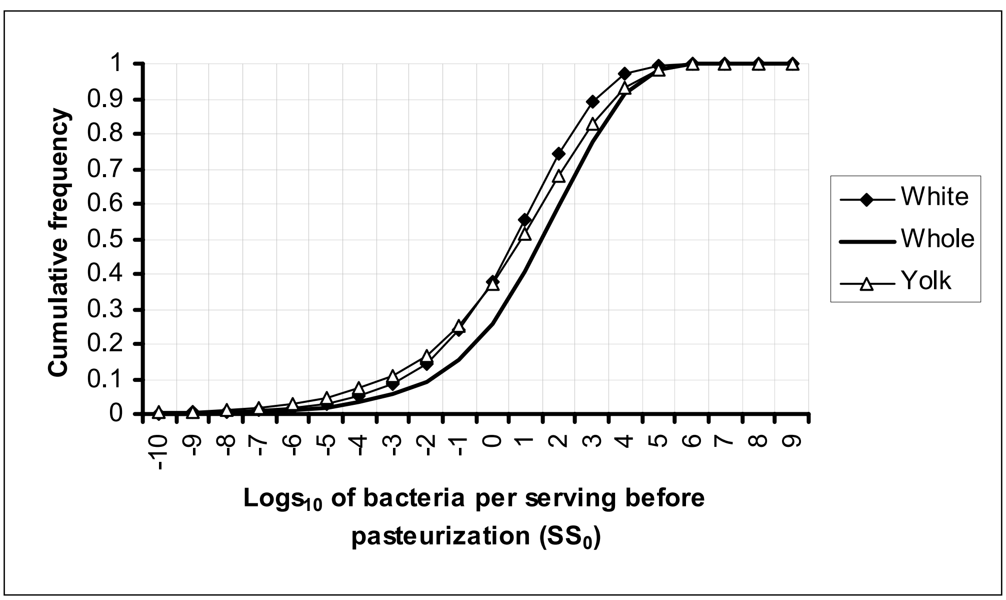

FIGURE 3-43 LOG_{10} BACTERIA PER SERVING IN DIFFERENT TYPES OF EGG PRODUCTS BEFORE PASTEURIZATION.

Figure 3-44 contains the same information as in Figure 3-43 but is presented as a frequency distribution. This makes it easy to visualize that a typical serving of egg product may contain 2 $\log_{10}$, or 100 bacteria before pasteurization. Figure 3-45, Figure 3-46, and Figure 3-47 compare cumulative frequency distributions for bacteria per ml and subsequent bacteria per serving for whites, wholes, and yolks, respectively.

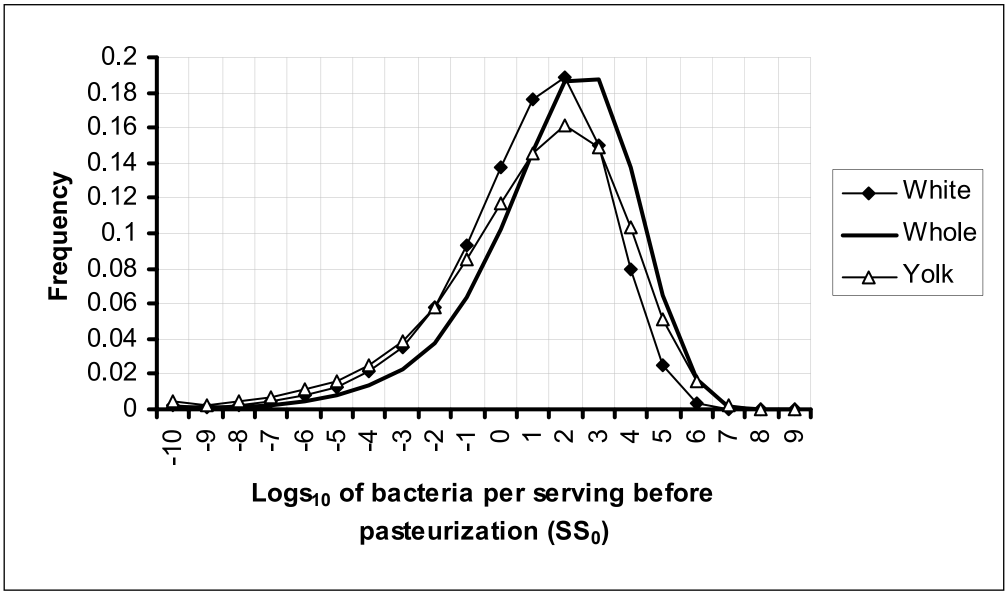

FIGURE 3-44 LOG10 BACTERIA PER SERVING IN DIFFERENT TYPES OF EGG PRODUCTS BEFORE PASTEURIZATION.

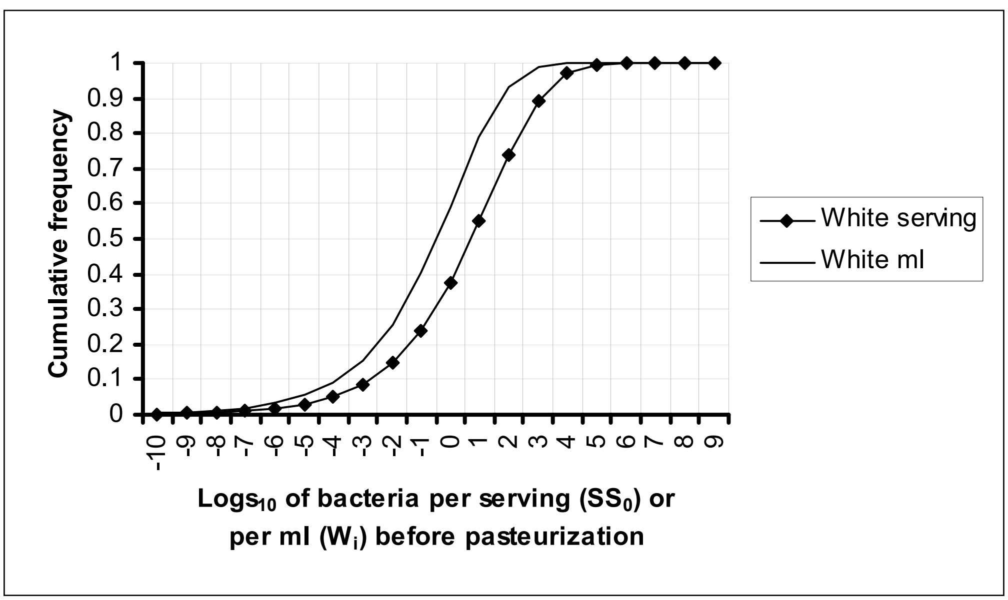

FIGURE 3-45 LOG10 BACTERIA PER ML AND PER SERVING BEFORE PASTEURIZATION FOR EGG WHITE.

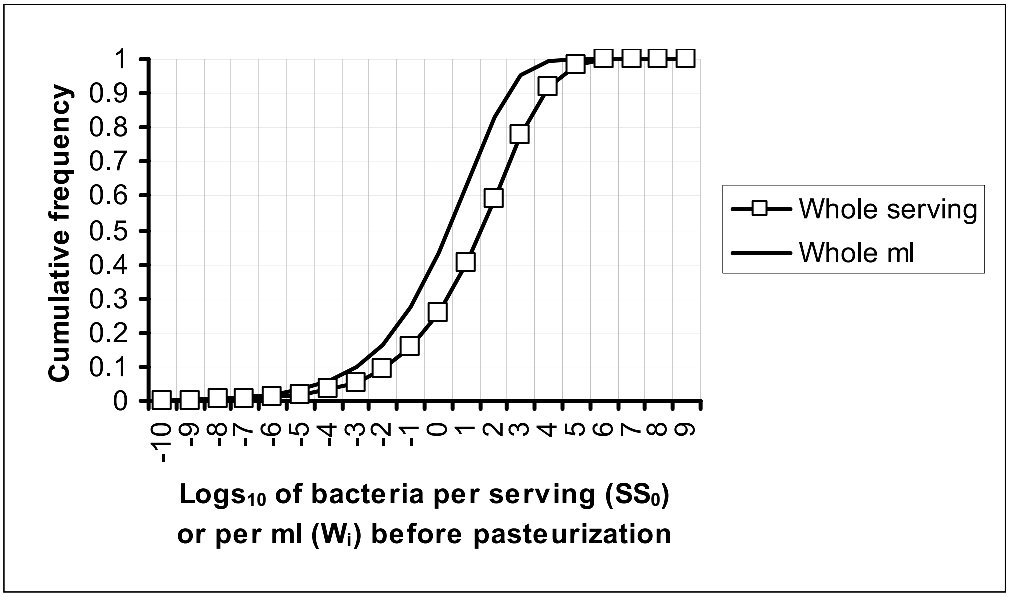

FIGURE 3-46 LOG$_{10}$ OF BACTERIA PER ML AND PER SERVING BEFORE PASTEURIZATION FOR WHOLE EGG.

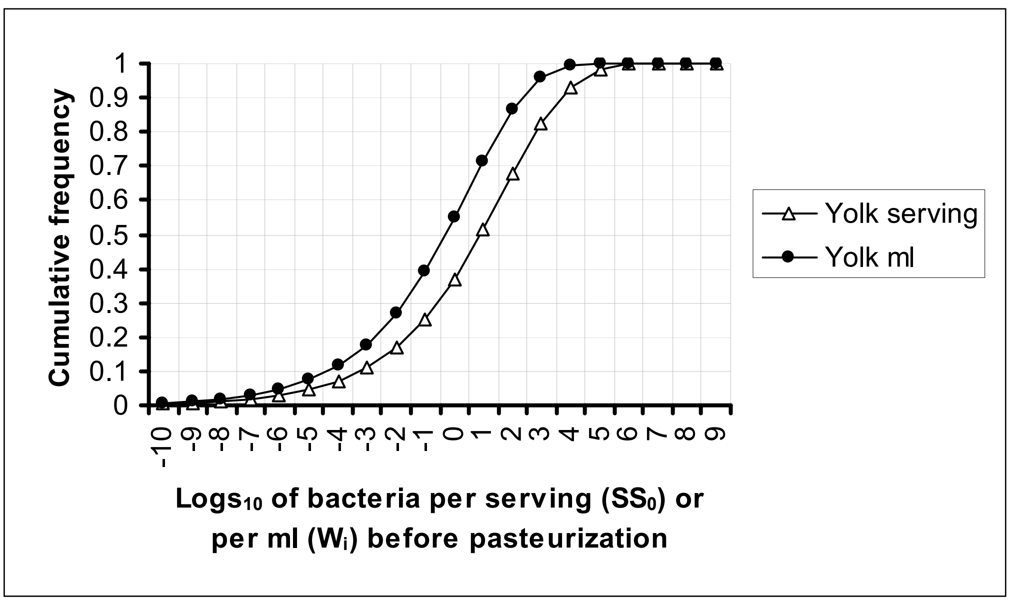

FIGURE 3-47 LOG$_{10}$ OF BACTERIA PER ML AND PER SERVING BEFORE PASTEURIZATION FOR EGG YOLK.

Pasteurization effectiveness, *P*

P was defined as the fraction of *Salmonella* that survive a pasteurization treatment. The input values for *P* for each egg product type are presented in Table 3-37 and are presented graphically below in Figure 3-48, which shows the fraction of bacteria that would survive after pasteurization.

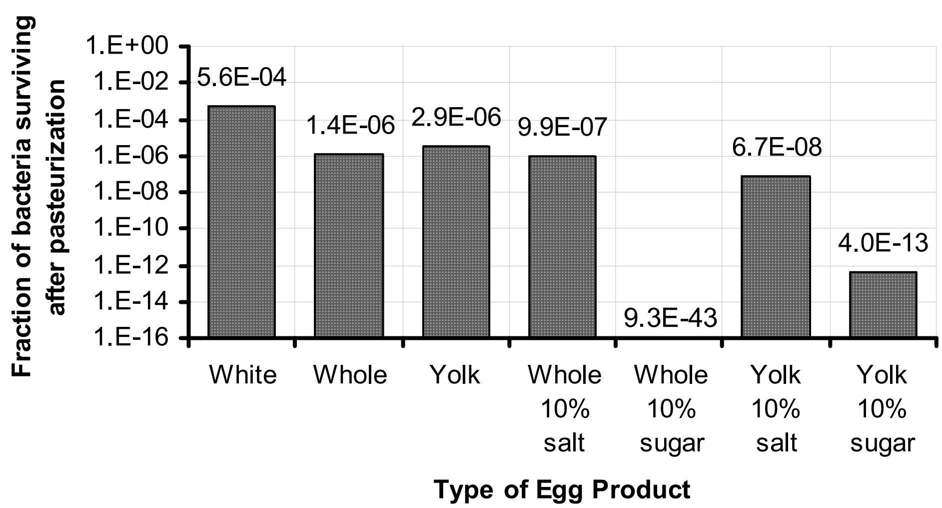

FIGURE 3-48 MODELED PASTEURIZATION EFFECTIVENESS FOR DIFFERENT TYPES OF EGG PRODUCTS.

Why Are Egg Products Pasteurized At Different Temperatures?

Egg products are pasteurized at different temperatures depending on whether the product is white, whole egg, or yolk, or whether the product has additives such as sugar or salt. Egg white coagulates at a lower temperature than whole egg which coagulates at a lower temperature than yolk. Additives increase the temperature of coagulation so yolk product with added sugar can be pasteurized at a higher temperature than white product. Attempting to pasteurize egg whites at the temperature used for egg yolks can result in cooking rather than pasteurization.

Note that liquid white product would be expected to have a relatively large fraction of bacteria surviving pasteurization compared to the other products. In contrast, there is no probability of bacteria surviving pasteurization in whole egg product with 10% added sugar. Solely considering time and temperature requirements from Table 3-37, one would expect egg whites to have more bacteria surviving because of the lower temperature. Similarly, egg product with additives is required to be heated to a higher temperature.

Temperature is an extremely sensitive input to the calculation for the pasteurization factor for egg white. Increasing the temperature from 56.67°C to 57.0°C decreases the pasteurization factor from 5.6 x 10^{-4} to about 1 x 10^{-4}. Increasing the temperature to 58°C decreases the pasteurization factor to about 1 x 10^{-8}, or an 8-$\log_{10}$ reduction due to pasteurization.

Figure 3-49 compares the expected $\log_{10}$ reductions due to pasteurization with the expected value of the distributions for *Salmonella* per serving. Except for egg white, each of the egg products has a higher expected $\log_{10}$ reduction than the expected value for *Salmonella* per serving. Thus, it is to be expected that egg white product will have a higher exposure distribution than the other egg products.

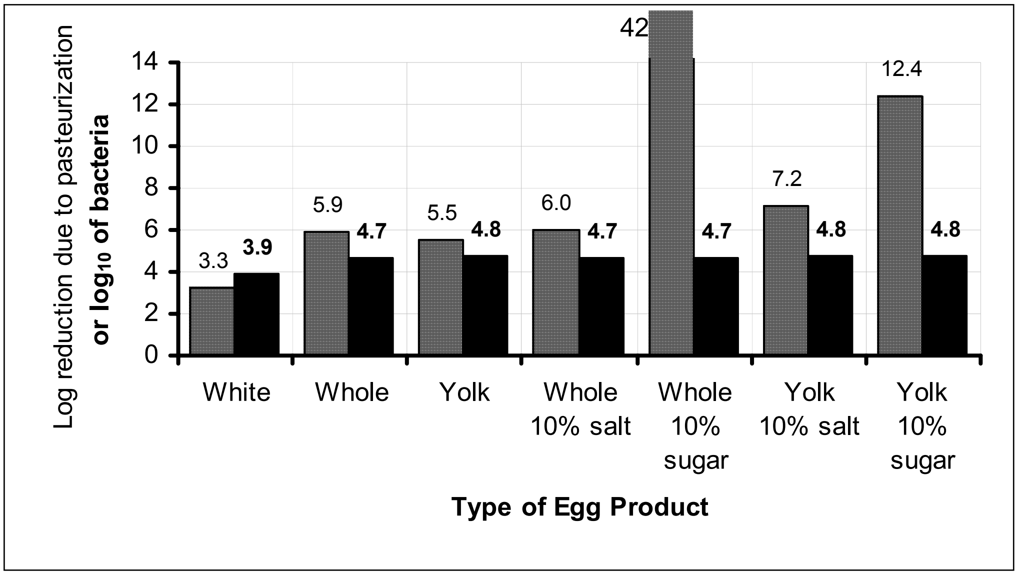

FIGURE 3-49 MODELED PASTEURIZATION EFFECTIVENESS FOR DIFFERENT TYPES OF EGG PRODUCTS COMPARED WITH THE EXPECTED VALUES FROM THE CONCENTRATION DISTRIBUTIONS.

<u>Growth effect after pasteurization, G_2</u>

The amount of *Salmonella* growth after processing is minimal because of the low storage temperatures at which the products are expected to be held. The model reflects these temperatures. No contaminated servings experienced as much as 2 $\log_{10}$ of growth and the maximum growth simulated for liquid white was less than 0.5 $\log_{10}$. Figure 3-50 shows the frequency distribution for G_2 for the three main classes of egg products.

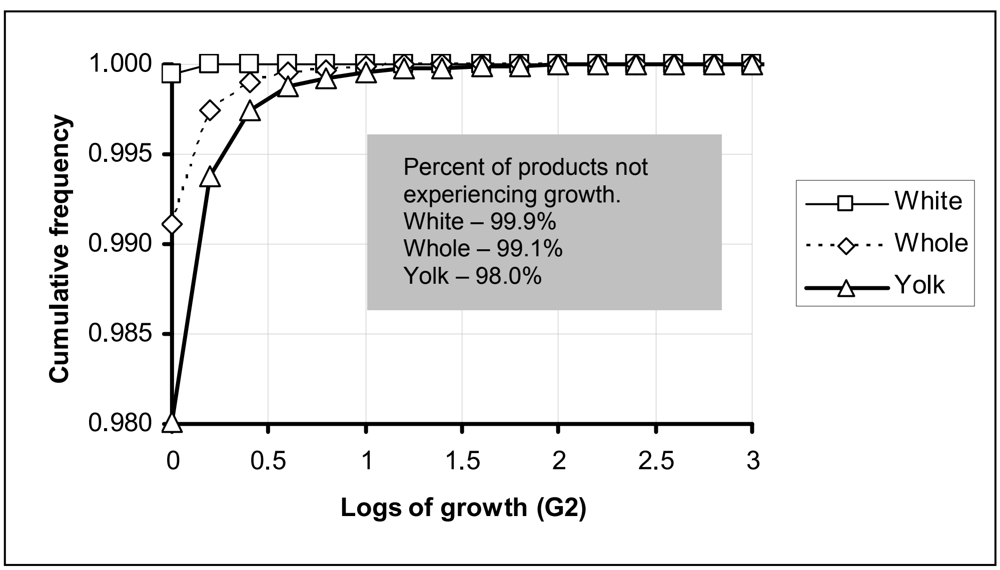

FIGURE 3-50 LOG_{10} GROWTH IN YOLK, WHOLE, AND WHITE FOLLOWING PASTEURIZATION (G_2).

Figure 3-51 replicates Figure 3-50 in the form of a frequency distribution on a $\log_{10}$ scale. It more readily demonstrates the difference between whole egg product and egg yolk product above 1 $\log_{10}$ of growth.

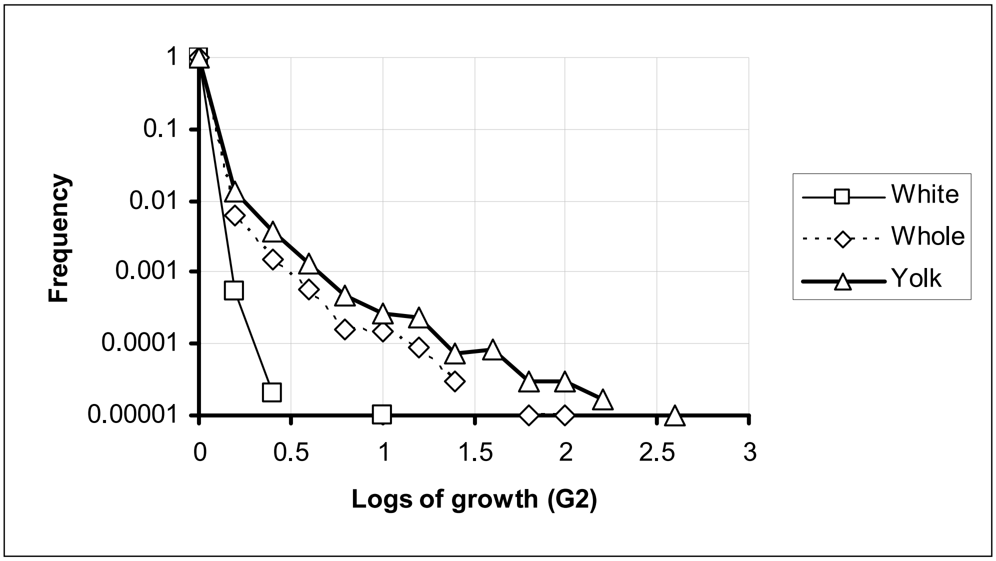

FIGURE 3-51 LOG$_{10}$ GROWTH IN YOLK, WHOLE, AND WHITE FOLLOWING PASTEURIZATION (G_2).

<u>Number of *Salmonella* per consumed serving</u>

The most useful output of the exposure assessment is the number of *Salmonella* consumed per serving for each of the seven different egg product types. Figure 3-52, Figure 3-53, Figure 3-54, Figure 3-55, Figure 3-56, Figure 3-57, and Figure 3-58 show the number of bacteria per serving for white, whole egg, yolk, whole egg with salt, whole egg with sugar, yolk with salt, and yolk with sugar, respectively. In each of these figures, both the x-axes and the y-axes are shown in the $\log_{10}$ scale. Frequency distributions rather than cumulative frequency distributions are shown because they allow easier viewing of the low frequencies. The y-axes are scaled from 10^{-9} (0.000000001), or one serving per billion servings, to 1, which represents every serving.

As might be expected, egg whites have the highest frequency distribution because of the relatively low number of $\log_{10}$ reductions due to pasteurization. Nevertheless, about 99.87% of prepared servings would be expected to have 0 bacteria present. Of the contaminated servings, over 99% would be expected to contain 1 *Salmonella*, and about 0.1% of the contaminated servings would be expected to contain 10 or more *Salmonella*. The other six product types have fewer numbers of contaminated servings. The modeled pasteurization effectiveness is so great for whole egg product with 10% added sugar that no contaminated servings are estimated.

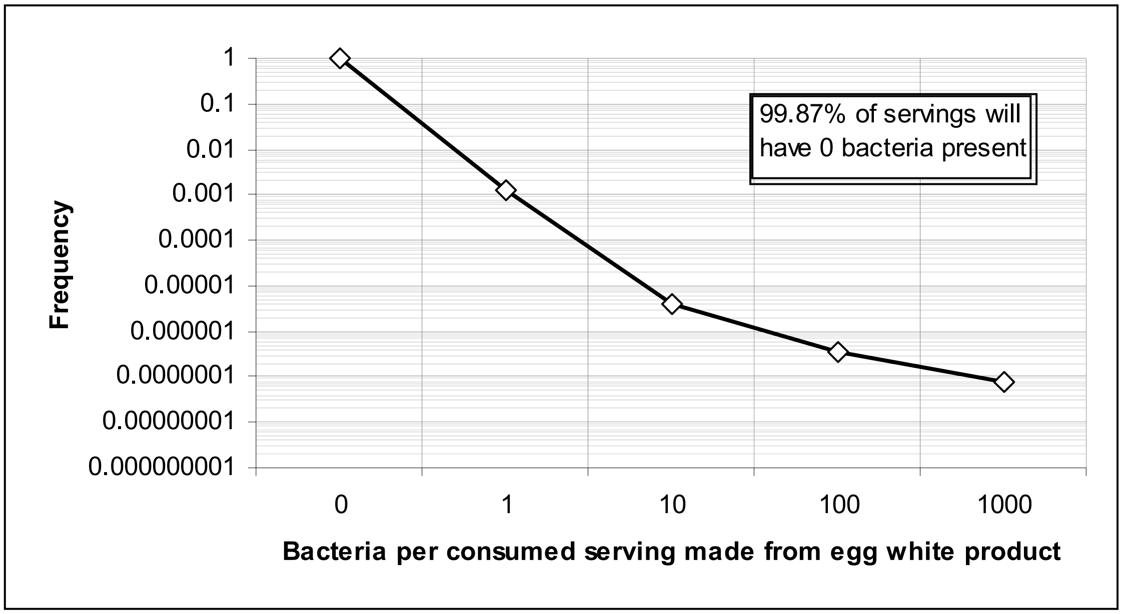

FIGURE 3-52 NUMBER OF SALMONELLA PER SERVING OF EGG WHITE PRODUCT AT CONSUMPTION.

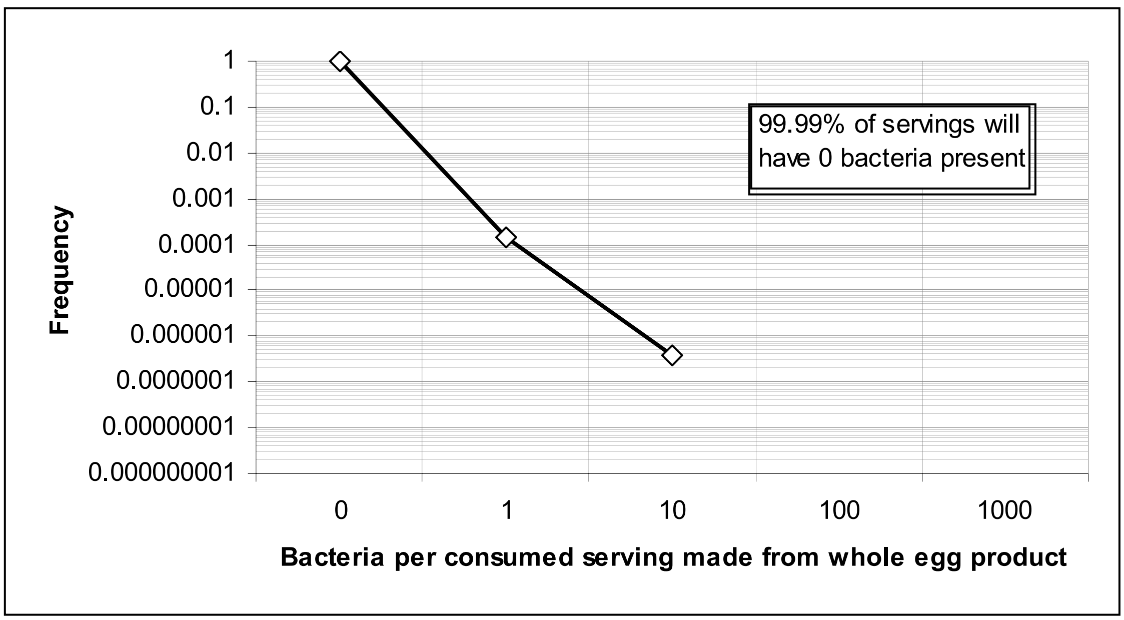

FIGURE 3-53 NUMBER OF SALMONELLA PER SERVING OF WHOLE EGG PRODUCT AT CONSUMPTION.

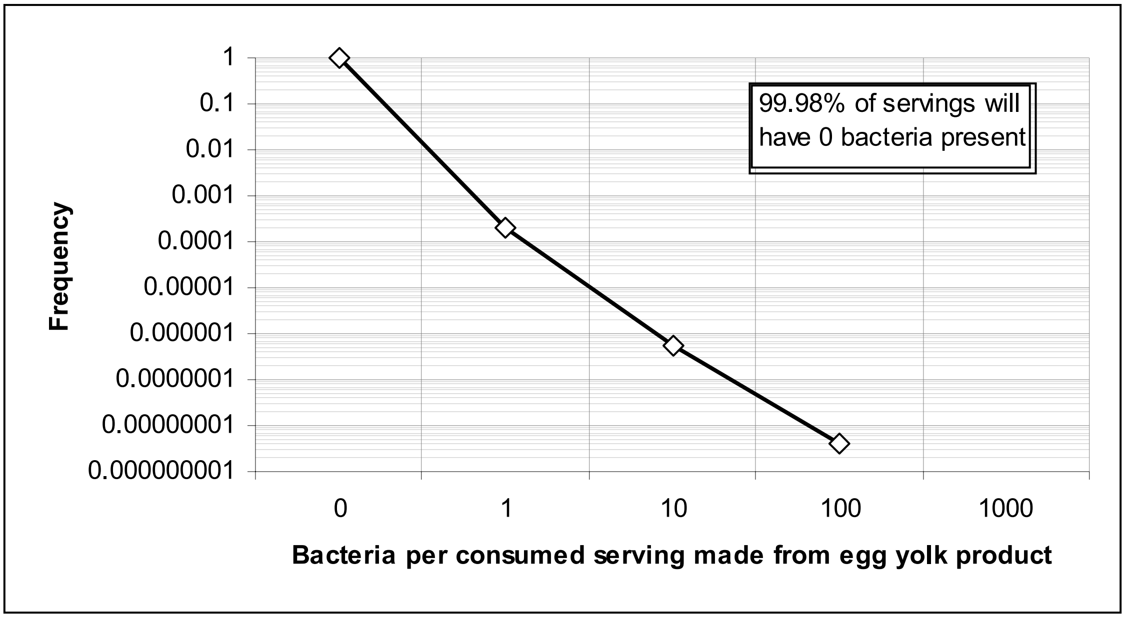

FIGURE 3-54 NUMBER OF *SALMONELLA* PER SERVING OF EGG YOLK PRODUCT AT CONSUMPTION.

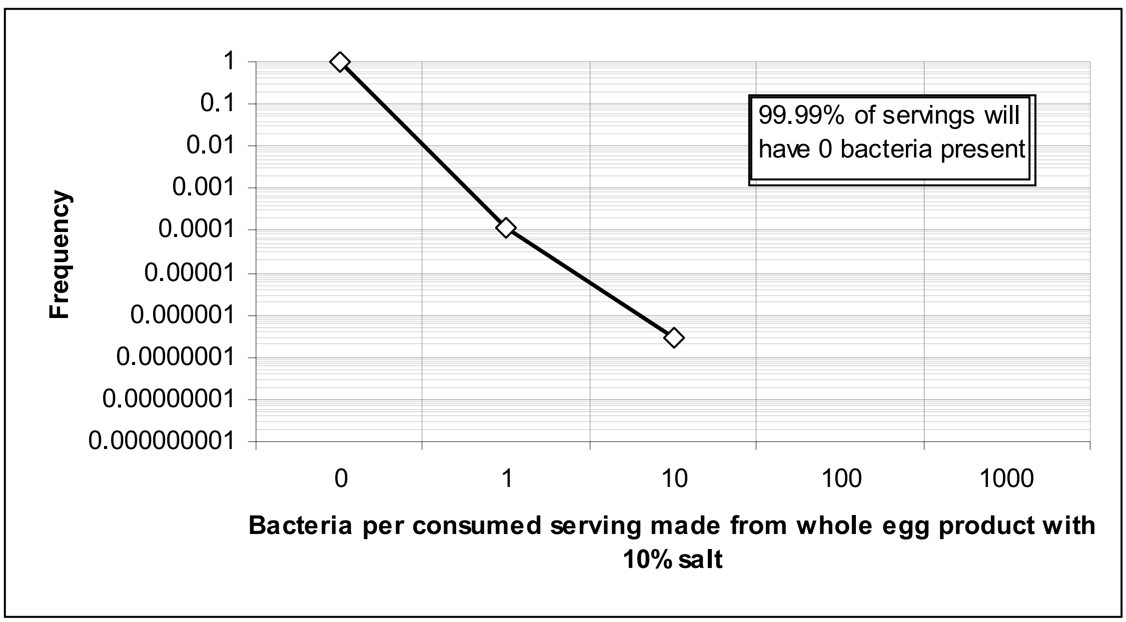

FIGURE 3-55 NUMBER OF *SALMONELLA* PER SERVING OF WHOLE EGG PRODUCT WITH 10% SALT AT CONSUMPTION.

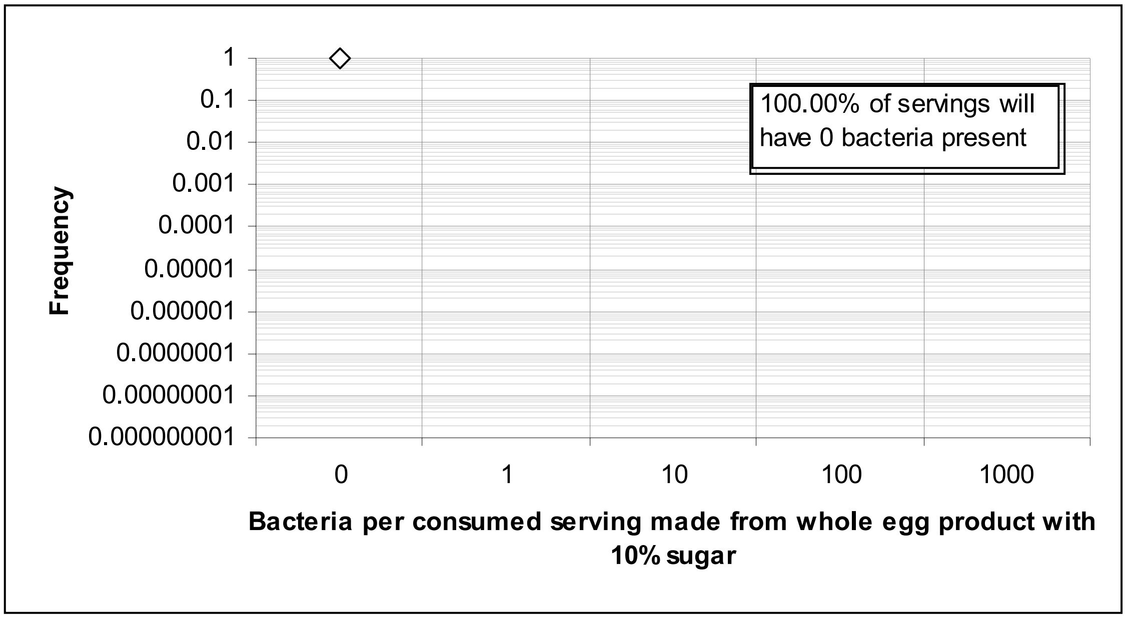

FIGURE 3-56 NUMBER OF *SALMONELLA* PER SERVING OF WHOLE EGG PRODUCT WITH 10% SUGAR AT CONSUMPTION.

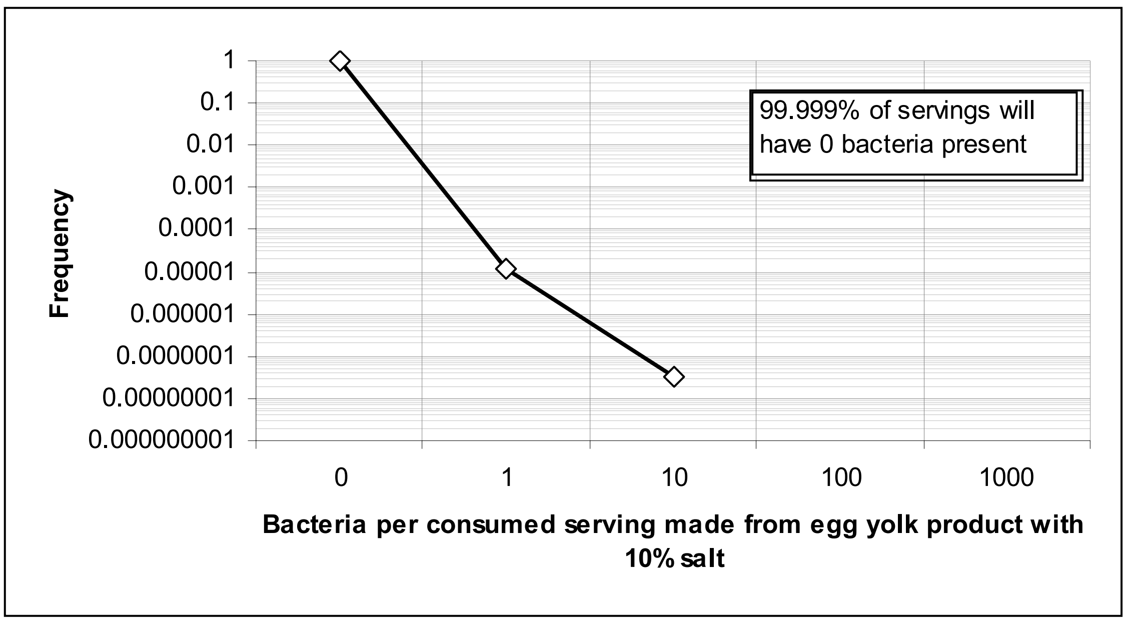

FIGURE 3-57 NUMBER OF *SALMONELLA* PER SERVING OF EGG YOLK PRODUCT WITH 10% SALT AT CONSUMPTION.

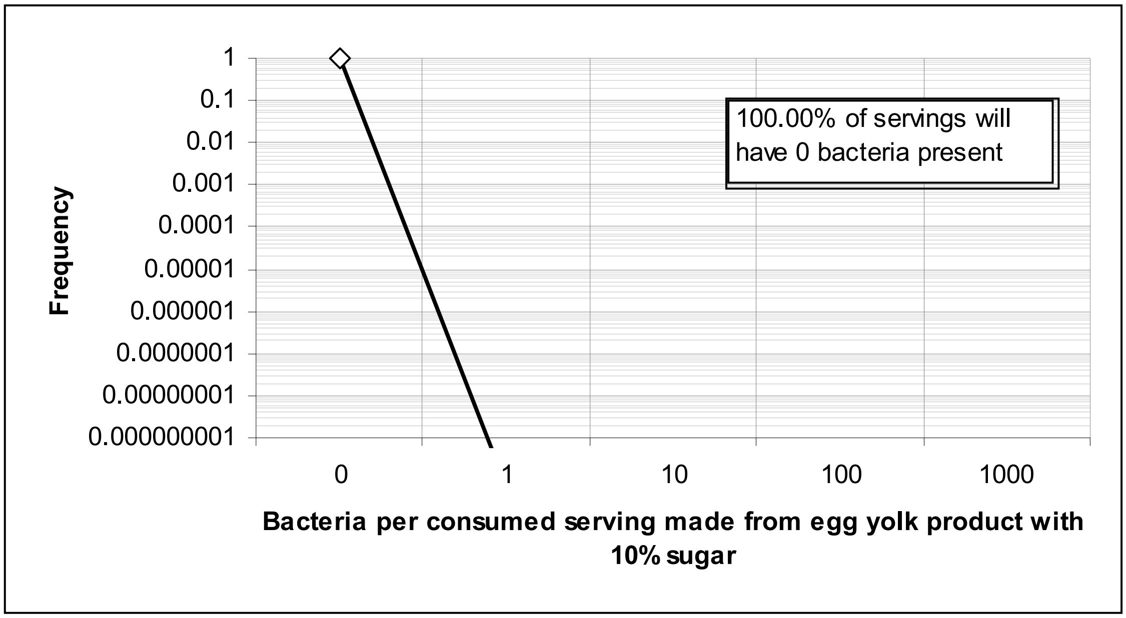

FIGURE 3-58 NUMBER OF SALMONELLA PER SERVING OF EGG YOLK PRODUCT WITH 10% SUGAR AT CONSUMPTION.

Table 3-42 shows the expected value for each of the egg product exposure distributions. This represents the average number of *Salmonella* to which a consumer would be exposed from one prepared serving.

TABLE 3-42 EXPECTED VALUE OF EXPOSURE DISTRIBUTION FOR DIFFERENT EGG PRODUCTS.

Egg Product	Expected Value of Exposure Distribution
White	1.4×10^{-3}
Whole	1.4×10^{-4}
Yolk	2.0×10^{-4}
Whole 10% salt	1.1×10^{-4}
Whole 10% sugar	$<10^{-16}$
Yolk 10% salt	1.2×10^{-5}
Yolk 10% sugar	7.5×10^{-11}

Table 3-43 shows the probability that a consumed serving would contain at least one *Salmonella* for each of the seven modeled egg products. Again, liquid egg white has the highest probability of exposure.

TABLE 3-43 PROBABILITY OF A CONSUMED SERVING CONTAINING AT LEAST ONE *SALMONELLA* BACTERIUM FOR DIFFERENT TYPES OF EGG PRODUCTS.

Egg Product	Probability of a Consumed Serving Containing at Least One *Salmonella*
White	1.3×10^{-3}
Whole	1.4×10^{-4}
Yolk	2×10^{-4}
Whole 10% salt	1.1×10^{-4}
Whole 10% sugar	$<10^{-16}$
Yolk 10% salt	1.2×10^{-5}
Yolk 10% sugar	7.5×10^{-11}

Table 3-44 compares the expected values of each of the egg product exposure distributions with the expected values of the pre-pasteurization serving distributions. Dividing the expected value of the exposure distribution by the expected value of the pre-pasteurization distribution results in a number that represents the combined mitigation multiplier effect due to pasteurization and cooking.

TABLE 3-44 COMPARISON OF DISTRIBUTIONS FOR *SALMONELLA* PRE-PASTEURIZATION AND AT CONSUMPTION.

Egg Product	Expected Value of Exposure Distribution	Expected Value of Pre-Pasteurization Distribution	Mitigation Multiplier Effect
White	1.4×10^{-3}	8.1×10^{3}	1.7×10^{-7}
Whole	1.4×10^{-4}	4.7×10^{4}	3×10^{-9}
Yolk	2×10^{-4}	5.9×10^{4}	3.5×10^{-9}
Whole 10% salt	1.1×10^{-4}	4.7×10^{4}	2.4×10^{-9}
Whole 10% sugar	$<10^{-16}$	4.7×10^{4}	$<10^{-16}$
Yolk 10% salt	1.2×10^{-5}	5.9×10^{4}	2.1×10^{-10}
Yolk 10% sugar	7.5×10^{-11}	5.9×10^{4}	1.3×10^{-15}

SUMMARY

Simulated servings frequently contained *Salmonella* prior to pasteurization for all three main product types. After pasteurization, however, contamination was infrequent and occurred only at low levels. Very little *Salmonella* growth occurs in egg products after pasteurization due to short storage times and low temperatures. Most servings are expected to be thoroughly cooked to effect a 12-$\log_{10}$ reduction. Therefore, cooking renders even heavily contaminated servings free of *Salmonella*. A small percentage of liquid egg product servings, however, will be consumed with no cooking. The contamination levels in these products at the time of consumption are generally the same as right after pasteurization. The effect of the contaminated servings on human health is examined in chapter 5. The sensitivity of risk estimates to various inputs and assumptions and the effect of interventions besides pasteurization are also investigated in chapter 4.

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