Percentage of bacteria that survive pasteurization, P

Pasteurization of shell eggs involves immersing the eggs in hot water for a prescribed length of time. The process should result in destroying some or all of the bacteria inside the egg. Different levels of effectiveness are achieved by changing the water temperature or the length of time the egg is immersed. The effectiveness of any combination of time and temperature is estimated from an equation. This effectiveness is expressed as the percentage of bacteria in an egg, P, that survive the pasteurization process.

One purpose of this risk assessment is to estimate the effectiveness of different pasteurization processes. Risk managers will use these estimates to determine a required level of effectiveness from pasteurization. Because the log reduction from pasteurization will vary with the particular characteristics of the eggs being pasteurized so could any eventual performance standards.

Although pasteurization is intended to reduce or eliminate bacteria within eggs, there is potential for an increase in risk in some eggs because pasteurization increases the temperature inside eggs and hastens YMB. YMB is a critical event for contaminated eggs because once it occurs, growth rates of bacteria within the egg dramatically increase. Any bacteria remaining inside an egg after pasteurization may be more likely to multiply faster during the post-pasteurization growth period, G_2, than they would in an egg that was not pasteurized.

As shown in Table 3-18 on the time in the pasteurizer and the temperature of the pasteurizer. The temperature inside the egg begins at some value depending on how the egg was handled prior to pasteurization, as predicted in G_1. This temperature then begins to equilibrate to the hot water temperature after the egg is immersed. Each egg "exits" the G_1 stage of the model with an internal temperature and a bacteria count. It enters the G_2 stage of the model with the same values.

The mechanics of simulating pasteurization for a single egg involve stepping through small time intervals to recalculate the internal egg temperature and the corresponding P value. The target value for P determines how long (i.e., in model terminology how many time increments) the pasteurization period is modeled. For each simulation, the target value for P is fixed for each pasteurized egg. The time it takes each egg to reach that P value will vary because the internal egg temperature will vary from egg to egg. We assign a fixed value of 58°C for the temperature of the pasteurizer's hot water.

While the pasteurizer is working to destroy bacteria, the internal egg temperature is also influencing the integrity of the yolk membrane such that it is likely to break down sooner. The algorithm presented in the G_1 section for $PYMB_t$ was developed based on ambient temperatures much less extreme than the temperatures experienced during pasteurization. The algorithm does not predict meaningful results for the high temperatures and short time periods experienced during pasteurization. Therefore, an alternative approach to determine the cumulative likelihood of YMB is needed. For $P(M_t)$, see Table 3-14. This approach uses the number of days until YMB (M) for given internal egg temperatures.

TABLE 3-17 NUMBER OF BACTERIA WITHIN EGG AT TIME *T* ASSUMING STOCHASTIC GROWTH PROCESSES.

Variable	Description	Estimation
$\mu(t)$	Exponential growth rate	See Table 3-15
q_0	Ratio of exponential lag rate (λ) to μ	$R = \frac{\ln\left(1 + \frac{1}{q_0}\right)}{\ln(2)}$, so q_0 = 0.03 (see Table 3-16)
$\lambda(t)$	Exponential lag rate	q_0 x μ
I	Integration of growth rates from time 0 to t	$\sum_0^t \mu(t) \times \Delta r$
$P(t)$	Cumulative likelihood of one organism being beyond its lag period duration at time t	$e^{-\sum_0^t \lambda x \Delta r} + \sum_0^t \left(e^{-1+\sum_0^t (\mu x \Delta r) - \sum_0^t (\lambda x \Delta r)} x \lambda x \Delta t \right)$
S_0	Number of organisms inside egg before growth begins	Initially a random value depending on egg type, E_i, but S_0 is iteratively updated during each time increment
$P(Growth)_t$	Likelihood that one or more organisms begin growth at time t	$1 - P(t)^{S_0}$
$E[r(t)]$	Average relative growth occurring at time t for all bacteria in egg	$e^{-\sum_0^t \lambda x \Delta r} + \sum_0^t \left(e^{-1+\sum_0^t (\mu x \Delta r) - \sum_0^t (\lambda x \Delta r)} x \lambda x \Delta t \right)$
$v(t,s)$	Intermediate calculation	$I - \sum_0^t \mu x \Delta t$
$\gamma(s)$	Intermediate calculation; the integral of exponential lag rate from time 0 to t	$\sum_0^t \lambda x \Delta r$
$V[r(t)]$	Variance in relative growth occurring at time t for all bacteria in egg	$\{2\int_0^t (e^{2v(t,s)} - e^{v(t,s)})e^{-\gamma(s)}ds + E[r(t)][1 - E[r(t)]]\} \div N_0$
$E[r(t)\|growth]$	Average relative growth for cells that grow inside egg	$\frac{\mathrm{E[r(t)]-(1-q)}}{\mathrm{q}}$
$V[r(t)\|growth]$	Variance in relative growth for cells that grow inside egg	$\frac{\mathrm{V[r(t)]\ -\ (1-q)q^{-1}(E[r(t)]-1)^2}}{\mathrm{q}}$
S_t	Number of bacteria within egg at time t	If $P(t)$<some critical value, then S_0; Otherwise $S_0 \times Lognormal(E[r(t) \| growth], V[r(t) \| growth])$

TABLE 3-18 DETERMINING PASTEURIZATION FACTOR.

Variable	Description	Estimation
α	Intercept term estimated from data	Fixed value (e.g., 67.2)
β	Slope term estimated from data	Fixed value (e.g., –1.2)
T	Ambient temperature in pasteurizer	Fixed value (e.g., 58°C)
B	Slope term as function of ambient pasteurizer temperature	$e^{\alpha + \beta T}$
A	Intercept term as function of ambient pasteurizer temperature	$-e^{4.18 + \ln(b)}$
t	Time in pasteurizer	Simulated
T_0	Internal egg temperature prior to pasteurization	Simulated output from G_1
k	Exponential cooling rate constant	Fixed value (e.g., 0.10 second–[1])
T_t	Internal egg temperature at time = t	$e^{(-kt)}(T_0 - T) + T$
P	Pasteurization factor given the time in pasteurizer and the temperature of the pasteurizer	$e^{-\sum_0^t e^{a(T)+b(T)\,x\,EggTermp_t}\,x\,\Delta t}$

Figure 3-16 plots the natural log of days until YMB (M) versus internal egg temperature. The values were generated using the algorithm in the G_1 section and determining the number of days when $P(M_t)$ was nearly 100%. The algorithm uses fixed internal egg temperatures and selects the time (in days) when the calculated $PYMB_t$ begins to plateau near 100% (i.e., where the cumulative likelihood of an egg's yolk membrane breaking down is about 100%).

Given the values plotted in Figure 3-16, a function is fit to the values to allow calculation of days until YMB for any egg temperature. This function,

$$Ln(YMBdays) = \left(1 - e^{k(EggTemp-10)}\right) \times Ln(100) \tag{3.18}$$

was estimated by minimizing the squared deviation between the values calculated using the algorithm described above and the values predicted by this function.

During each time increment in the pasteurization model, a value for M is calculated based on the internal temperature at that time. Recall that $P(M_t)$ is the cumulative probability of YMB. During pasteurization, this cumulative probability is incremented by $\frac{\Delta t}{M}$, where Δt is the size of time increment.

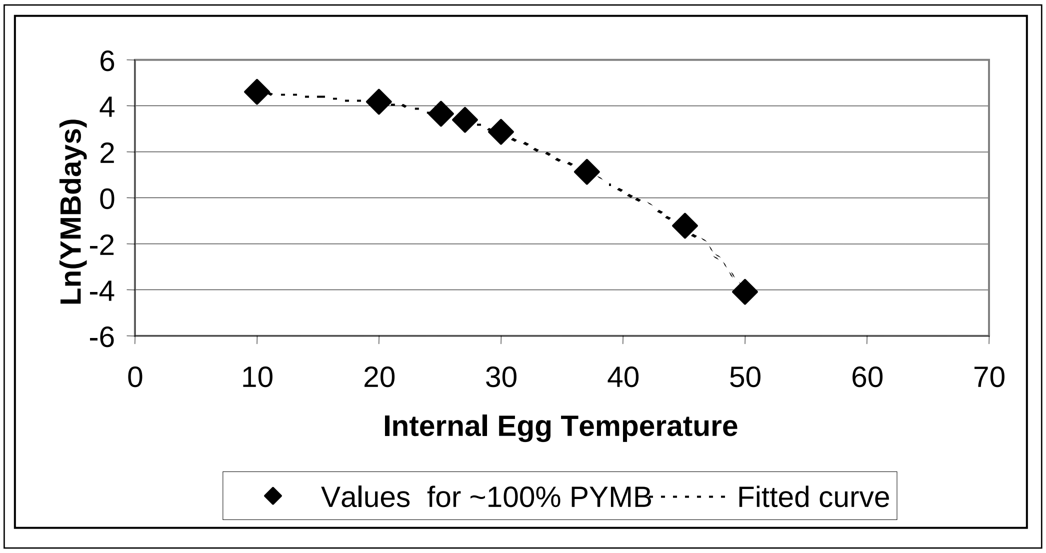

FIGURE 3-16 INTERNAL EGG TEMPERATURE VS. LN(YMB DAYS).

As an alternative to using, a published function for M ($M = 10^{2.09 - 0.043 \times T_t}$ is also available.[7] This function is easier to work with but predicts generally fewer days to YMB than that shown in Figure 3-16. The consequence of this alternative function is to increase $P(M_t)$ at higher temperatures more slowly. Thus, YMB is less likely to occur. The different effect of this function on model outputs is considered in the sensitivity and uncertainty analysis. The baseline model uses the function shown in Figure 3-16 because that function is directly related to the $P(M_t)$ algorithm used in G_1 and G_2.

Growth effect after processing, G_2

This section presents background material, mathematical concepts, derivation of inputs, functional relationships, and computer programming topics that concern growth of SE in contaminated eggs after processing (G_2). In the conceptual model, the amount of SE growth per egg after processing is represented as a multiplier, G_2. This represents the number of SE in an egg at the time of consumption resulting from handling and storing an egg after processing until the egg is consumed. As with growth before processing, growth in an individual egg after processing depends on storage time, storage temperature, and the cooling rates for eggs in particular storage conditions. The effect of the location of contamination and immunologic characteristics are the same as for growth before processing. The output of G_2 is a probability distribution reflecting the amount of growth that would be expected in the population of SE-contaminated eggs from the processor to consumption.

<u>Derivation of storage times and temperatures and exponential cooling constants</u>
The modeling approach for G_2 is similar to that for G_1. The number of bacteria, the location of contamination, and the internal egg temperature predicted in G_1 as well as the pasteurization step, P, are carried over to G_2 After predicting SE growth in G_1 and possible SE decline in pasteurization, the remainder of the model considers the following steps for each egg: post-

processing storage; retail transportation or transportation to a distributor; retail storage or storage at a distributor; home transportation or transportation to a hotel, restaurant, or institution; and home storage or storage at a hotel, restaurant, or institution.

The number of pathways that eggs can take after processing probably exceeds the number of pathways they can take before processing. Eggs may be shipped directly to a retail store after processing or they may pass through intermediate distributors. Eggs may be stored and prepared in a restaurant setting rather than in the home. The evidence available for storage practices after processing, however, is sparse. Distributions for storage practices are inferred from recorded practices for other types of products or recommended practices for eggs. The model treats eggs as if they pass through all five steps.

Determination of internal egg temperature, YMB, and bacteria growth follows the procedures detailed for G_1. The principal differences between G_1 and G_2 are the storage times and temperatures for each of the new steps and the heat transfer dynamics after processing when eggs are transferred to different types of containers.

Storage times

Eggs are stored after processing, during transport, at retail, during transport to the home, and in the home. The length of time any egg is stored in each of the locations can be described by a probability distribution. Data for estimating distributions for storage times at each location are presented in this section. The estimated distributions are also shown. Table 3-19 shows the available data for time inputs.

TABLE 3-19 AVAILABLE DATA FOR TIME INPUTS FOR G_2.

Retail Storage (represents post-processing, retail transportation, and retail storage)[a]		**Home Transportation**[b]			
			% Frequency at Listed Outside Temperatures		
Days Since Egg Processing when Consumer Purchased	**% Frequency**	**Time Out of Refrigeration in Minutes**	**<70°F (21.1°C)**	**70 – 89°F (21.1-31.7°C)**	**>89°F (31.7°C)**
1 – 7	25%	0 – 15	0	0.4	0.4
8 – 14	45.2%	16 – 30	3	6	4
15 – 21	16%	31 – 45	15	14	17
22 – 28	9.2%	46 – 60	25	27	24
29 – 35	4%	61 – 75	27	24	26
36 – 42	0%	76 – 90	16	13	16
43 – 49	0.6%	91 – 105	11	10	7
		106 – 120	3	4	3
		>120	1	3	2
		n =	143	545	245

[a]Source: Bell et al.[8]
[b]Source: Audits International[9]

Data were available for storage time for only two of the five steps. The data for retail storage, however, are more informative than might be apparent at first. Bell[8] reports on the total time between processing and purchase by consumers. Thus, the data in the table above represent the total storage time in the post-processing, retail transportation, and retail storage steps. As with the data for G_1, these data were fit to lognormal distributions. Figure 3-17 compares the cumulative lognormal distribution with the cumulative frequency data from the retail storage data in Table 3-19.

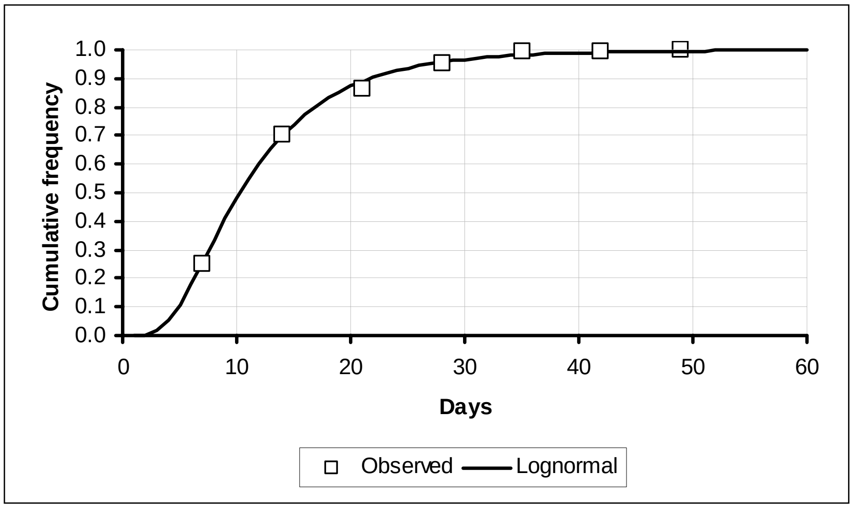

FIGURE 3-17 COMPARISON OF OBSERVED AND PREDICTED RESULTS FROM A LOGNORMAL DISTRIBUTION FOR RETAIL STORAGE TIME.

Audits International[9] reports time, in days, of transportation to the home for three different ambient temperature ranges; a chart depicting the relative frequencies of these times for each of the ambient temperature ranges is shown in Figure 3-18.

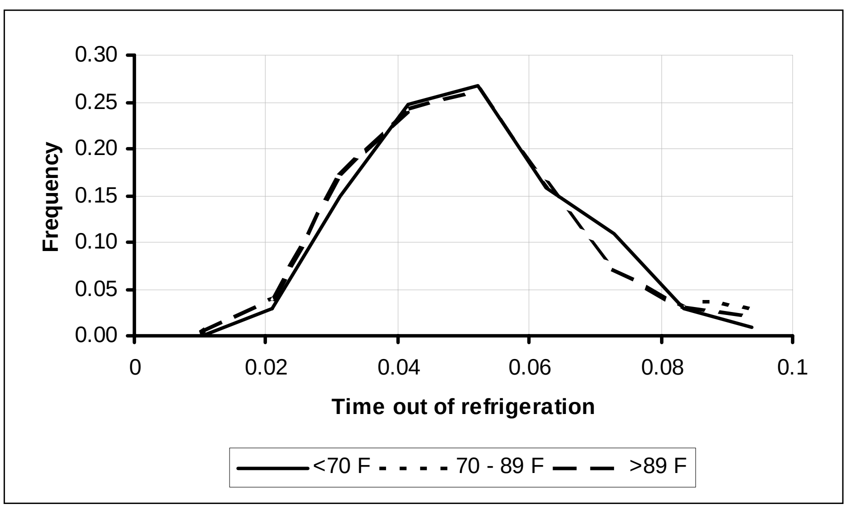

FIGURE 3-18 RELATIVE FREQUENCIES OF TIME, IN DAYS, OUT OF REFRIGERATION FOR THREE DIFFERENT TEMPERATURE RANGES.

Because there appears to be relatively little difference in the three frequency distributions, the three distributions are integrated. Figure 3-19 compares the observed data with a lognormal distribution.

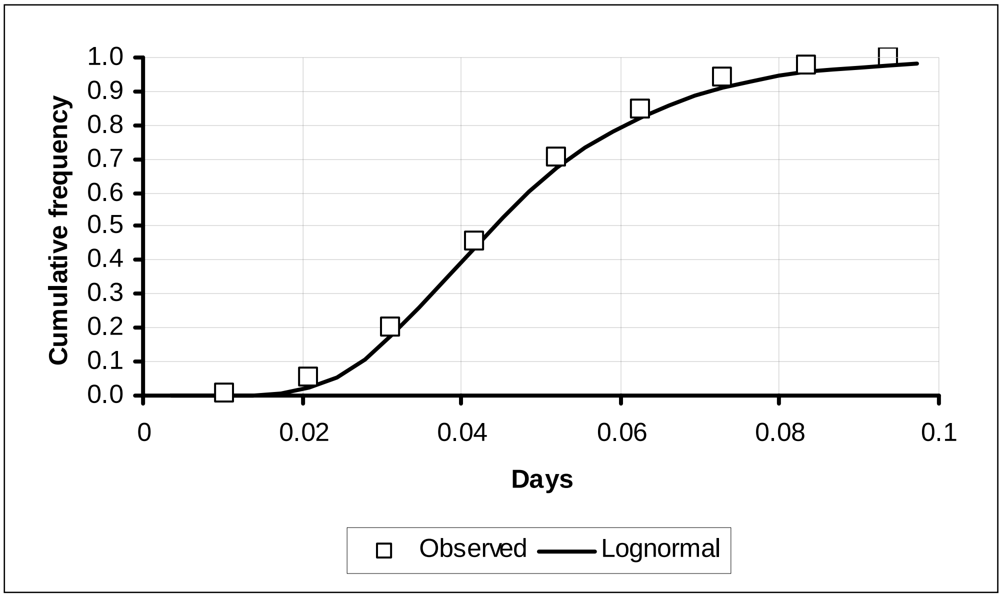

FIGURE 3-19 COMPARISON OF OBSERVED AND PREDICTED RESULTS FOR A LOGNORMAL DISTRIBUTION FOR RETAIL STORAGE TIME.

Although the information above provides an estimate of the total time elapsed between the finishing of processing and the purchasing of eggs at retail, no data specifically describe post-processing storage time or the time it takes to transport eggs between the processor and retail. The post-processing storage times occur after egg processing and before the eggs are transported from the processor to retail. Therefore, default distributions for post-processing storage, and transportation times are developed and then subtracted from the total time of storage to estimate retail storage time. As a default, post-processing storage time was modeled with a lognormal distribution where the mean was equal to the weighted mean of the two pre-processing storage time distributions, and the standard deviation was equal to the larger of the two standard deviations for pre-processing storage time. The two means for pre-processing storage time are –0.04 for the 86.5% of eggs that undergo off-line processing and 0.67 for the 13.5% of eggs that undergo in-line processing. Thus, the input mean to the lognormal distribution is –0.04 x 0.865 + 0.67 x .0135 » 0.056. Of the two standard deviations, 1.33 and 0.89, the larger is chosen.

Similarly, no data specifically describe the time for transportation to a retailer. A value of 12 hours was chosen as a default mean for a lognormal distribution. The standard deviation was set to the same as used for layer house storage, on-farm storage, and transportation to the processor.

The lognormal distribution shown in Figure 3-19 represents the total storage time for the post-processing, retail transportation, and retail storage steps. To determine the modeled times for each of these steps, the following algorithm is used during model simulation: 1) one total storage time for all three steps is sampled from the distribution; 2) post-processing storage time is sampled from its default distribution; 3) retail transportation time is sampled from its default distribution; 4) retail storage time is equal to the total storage time minus the post-processing and retail transportation times; and 5) if retail storage time is less than 0.5 days, then retail storage time is set to 0.5 days, and the post-processing storage time is now set to the total storage time minus the retail transportation and retail storage times. This algorithm ensures that total storage time from processing through consumer purchase will mirror the data shown in Table 3-19.

There are no data describing the length of time eggs are stored by the end user before preparation. There are, however, recommended storage practices for eggs; specifically, FSIS states that raw eggs in the shell may be safely stored for 3 to 5 weeks.[10] The mean of the lognormal distributions was set as the geometric mean of 1 day and 35 days of storage. The standard deviation was set at the value used for other steps in G_1 and G_2. Table 3-20 shows the inputs for storage time for G_2.

TABLE 3-20 PARAMETERS FOR LOGNORMAL DISTRIBUTIONS FOR TIME OF EGG STORAGE AT DIFFERENT MODEL POINTS.

Input	Supported by Data?	Time (Ln(Days)) Mean	Std Dev
Post-processing	No	0.05	1.33
Retail transportation	No	-0.69	0.59
Retail storage	Yes	2.33	0.59
Home transportation	Yes	-3.12	0.37
Home storage	No	1.78	0.59

Storage temperatures

The ambient temperature of storage for an egg during post-processing, transportation, retail, home transportation, and home storage is used to predict the internal egg temperature that determines the amount of *Salmonella* growth in the egg. This is a vector of five values for each egg. The ambient storage temperature at each of these stages can be described by a probability distribution. Data for estimating distributions for storage temperatures at each location are presented in this section. The estimated distributions are also shown. Table 3-21 shows the available data for temperature inputs.

Data were available for storage temperatures for three of the five steps. All data came from a single source.[9] Product temperatures were reported for the following products in retail display cases: liquid dairy, semi-solid dairy, pre–packaged lunchmeat, ground beef, fish fillet, sliced meat, and potato salad or equivalent. Additionally, temperatures were recorded in semi-solid dairy product in the backroom refrigerator. Temperatures for home transportation and home storage also came from semi-solid dairy products. Because of the availability of information for semi-solid dairy products and because these products were more likely to be stored in the same cases as eggs, semi-solid dairy product temperatures were used as a proxy for egg storage temperatures.

TABLE 3-21 AVAILABLE DATA FOR TIME INPUTS FOR G_2.

Retail Storage			**Home Transportation**		**Home Storage**	
Dairy Semi-solid	**Frequency of Temperatures in**		**Outside Ambient Temperature**		**Home Refrigerator Product Temperatures**	
Temperature (°F)	Retail Refrigerator	Backroom Refrigerator	Temperature (°F)	Frequency (%)	Temperature (°F)	Frequency (%)
≤26	0.004	0.030	<55	1.0	≤32	9.0
27 – 29	0.005	0.010	55 – 59	2.0	33 – 35	10.0
30 – 32	0.039	0.089	60 – 64	5.0	36 – 38	25.0
33 – 35	0.059	0.099	65 – 69	7.0	39 – 41	29.0
36 – 38	0.167	0.325	70 – 74	12.0	42 – 44	18.0
39 – 41	0.325	0.276	75 – 79	12.0	45 – 47	5.0
42 – 44	0.236	0.108	80 – 84	20.0	48 – 50	3.0
45 – 47	0.069	0.020	85 – 89	15.0	51 – 53	0.4
48 – 50	0.059	0.030	90 – 94	14.0	54 – 56	0.5
51 – 53	0.020	0.008	95 – 99	8.0	57 – 59	0.4
54 – 56	0.008	0.002	100 – 104	4.0	60 – 62	0.1
57 – 59	0.003	0.002	≥105	0.6	63 – 65	0
60 – 62	0.004	0.002	*n* =	970	≥66	0.1
63 – 65	0.000	0.000			*n* =	939
≥66	0.001	0.000				
n =	972	515				

Source: Audits International.[9]

Data for retail storage temperatures came from two locations in the store: the retail display case and, when permission was granted to the auditor, the backroom refrigerator. Frequency distributions of temperature in these two locations are shown in Figure 3-20.

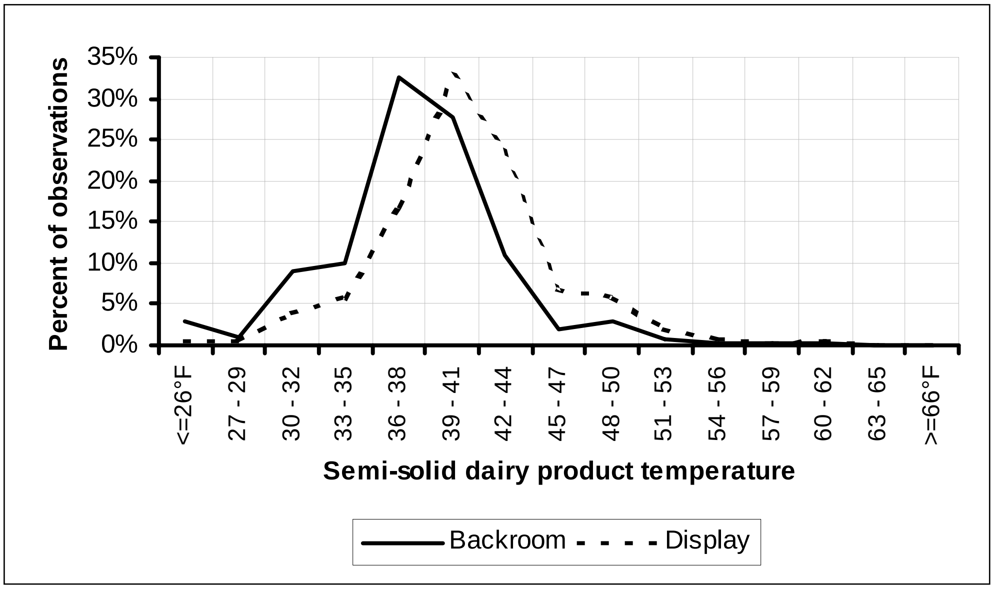

FIGURE 3-20 RECORDED TEMPERATURES FOR SEMI-SOLID DAIRY PRODUCTS.
Source: Audits International.[9]

The two frequency distributions shown in Figure 3-20 are similar with the backroom product temperature being shifted to lower temperatures. It is likely that eggs would spend some time after transportation in a backroom refrigerator and then moved to a display case as needed. Temperature is modeled as a single distribution because there is no information regarding the relative times of storage in each location and the semi-solid dairy product serves only as a proxy for eggs. Lognormal distributions were fit to the data for G_2 temperature distributions in the same manner as for the G_1 temperature distributions. Figure 3-21 compares the observed data with a lognormal distribution for retail storage temperature.

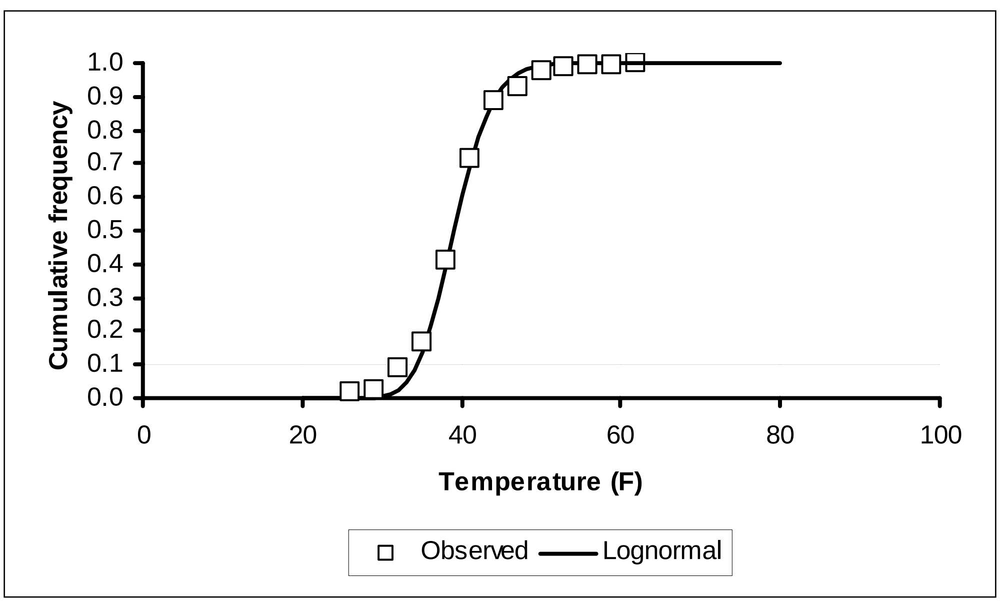

FIGURE 3-21 COMPARISON OF OBSERVED AND PREDICTED RESULTS FROM A LOGNORMAL DISTRIBUTION FOR RETAIL STORAGE TEMPERATURE.

Figure 3-22 compares observed data with a lognormal distribution for home transportation temperature.

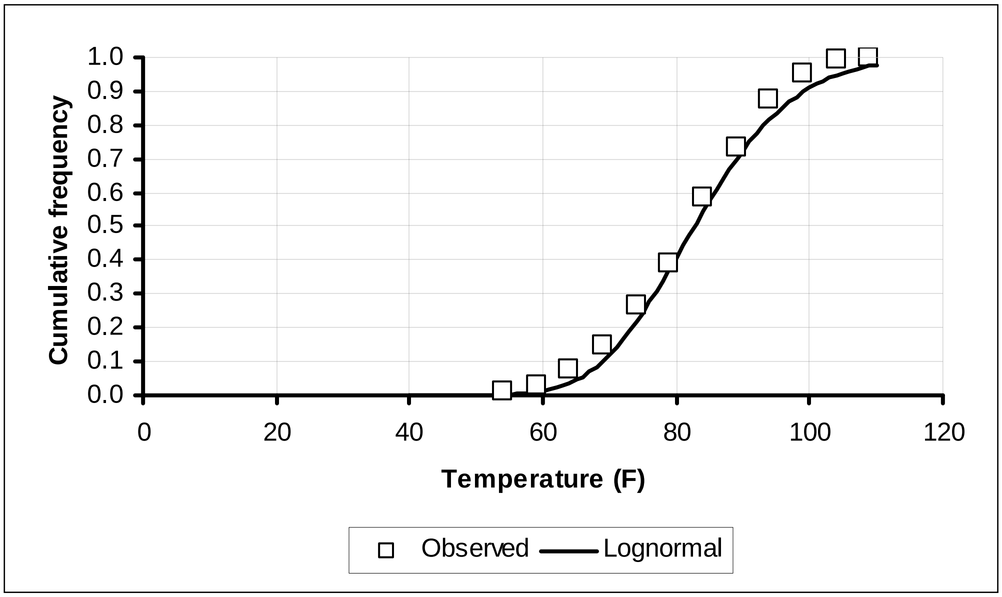

FIGURE 3-22 COMPARISON OF OBSERVED AND PREDICTED RESULTS FROM A LOGNORMAL DISTRIBUTION FOR HOME TRANSPORTATION TEMPERATURE.

The temperature measured in home refrigerators was taken in semi-solid dairy product 24 hours after the product was placed in the refrigerator. Thus, the temperature is considered an adequate representation of the ambient temperature. Figure 3-23 compares observed data with a lognormal distribution for home storage temperature.

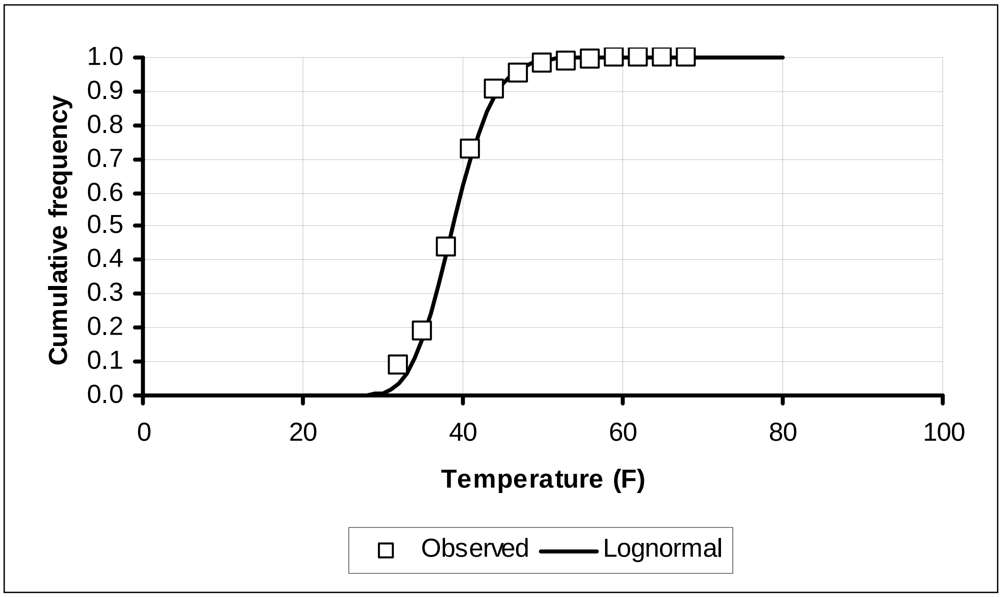

FIGURE 3-23 COMPARISON OF OBSERVED AND PREDICTED RESULTS FROM A LOGNORMAL DISTRIBUTION FOR HOME STORAGE TEMPERATURE.

There was no direct evidence describing the temperature of post-processing storage to which eggs would be exposed. Consequently post-processing storage temperature is assumed similar to pre-processing storage temperature. Nevertheless, it is easy to imagine ways in which storage temperatures for eggs before processing could be quite different from storage temperatures for eggs after processing. As with post-processing storage time, the in-line and off-line storage temperature distribution means were averaged with producers considered to represent in-line eggs and accounting for 13.5% of the distribution, while packers were considered off-line and accounted for 86.5% of the distribution. Because all of the standard deviations for storage temperatures were similar, the largest standard deviation was used for post-processing storage temperature.

No direct evidence is available that summarizes temperatures of vehicles used for transporting shell eggs to a retail establishment. It is likely that the vehicles used to transport eggs from the processor would not be the same vehicles as those used to transport eggs to the processor. Some simplifying assumptions have been made, however. It seems reasonable to assume that vehicles transporting eggs from a processor to retail or a distributor would be refrigerated. Consequently, the information on distribution of temperatures during transportation to the processor was used to develop the distribution for temperature during transportation from the processor.

Table 3-22 shows the parameters for lognormal distributions for temperature of egg storage at different model points.

TABLE 3-22 PARAMETERS FOR LOGNORMAL DISTRIBUTIONS FOR TEMPERATURE OF EGG STORAGE AT DIFFERENT MODEL POINTS.

		Temp °C	
Input	**Supported by Data?**	**Mean**	**Std Dev**
Post-processing	No	3.87	0.15
Retail transportation	No	3.94	0.15
Retail storage	Yes	3.66	0.10
Home transportation	Yes	4.42	0.14
Home storage	Yes	3.66	0.11

Exponential cooling rates

The exponential cooling rates applicable to stages in G_2 determine how fast an egg cools to the ambient storage temperature. The cooling rates reflect the manner in which eggs are stored. The manner of storage includes the packing material itself (e.g., cardboard or Styrofoam) and how an egg is stacked among all stored eggs. This section describes how exponential cooling rates are modeled during post-processing, transportation, retail, home transport, and home storage. The approach used here is similar to that described previously for G_1.

Post–processing storage

After processing, eggs are assumed to be placed in cases and pallets for distribution. These eggs would have a cooling constant of 0.01. The model assumes that 1% of eggs would be non–palletized. These eggs would have a cooling constant of 0.1.

Retail transportation or transportation to a distributor
All eggs are assumed to be packaged in cases with flats or cartons and placed on pallets for transportation. Thus, the cooling constant for transportation is identical to that for post-processing storage.

Retail storage or storage at a distributor
No information describes the storage practices for eggs in retail facilities and other types of distributors. We assume that regardless of where eggs are eventually consumed they would be stored in cases or on metal racks of dozens. These would have an exponential cooling constant value of 0.1.

Home transportation or transportation to a hotel, restaurant, or institution
Eggs are assumed to be transported in cases to institutional users and in sacks of groceries to home users. Consequently, an exponential cooling constant value of 0.1 is assigned for transportation from a retail store to a home.

Home storage or storage at a hotel, restaurant, or institution
Eggs used in the home are assumed stored in the individual carton or in an egg tray in the refrigerator. These eggs would have an exponential cooling constant of 1.0. Eggs stored in an institutional setting would be stored in cases and thus have an exponential cooling constant of 0.1. Table 3-23 shows the exponential cooling constants used in the model. Note that a cooling constant of 0.01 represents storage in pallets, and a cooling constant of 0.1 represents storage in individual cases or racks. These cooling constants are thus for the central egg, and the cooling constant for a specific egg is adjusted in accordance with the equations provided in the description for G_1.

TABLE 3-23 FRACTION OF THE CENTRAL EGGS AT DIFFERENT COOLING CONSTANTS IN THE STEPS BEFORE PROCESSING.

Location	**Fraction of Central Eggs at Given *k* Value**		
	0.01	**0.1**	**1**
Post-processing storage	0.99	0.01	
Retail transportation	0.99	0.01	
Retail storage	0.20	0.80	
Home transportation		1.00	
Home storage		0.55	0.45

Percentage of bacteria surviving cooking, C

After an egg has moved from the layer house, through the processor, through the retail store and has been stored at home, it is finally used to prepare a meal. Meal preparation may involve cooking. Cooking can reduce the number of bacteria in an egg. The effectiveness of cooking is measured as the percentage of bacteria that survive the cooking process, *C*. Cooking effectiveness can vary because of a multitude of factors; therefore, *C* is best described using a probability distribution. This section describes the data and analysis for estimating this distribution.

TABLE 3-24 THERMAL DEATH RATES FOR SE.

Method of Cooking	Cooking Time (minutes [± S.E.])	Mean Inoculum (log_{10} cfu/gm yolk ± S.E.)	Mean Number of Survivors (log_{10} cfu/gm yolk ± S.E.)
Boiling[a]	4	6.81 ± 0.06	5.87 ± 0.27
Frying sunny side up[a]	1.6 ± 0.2	6.90 ± 0.5	5.14 ± 0.2
Frying over easy[b]	2.4 ± 0.2	6.88 ± 0.4	<1
Scrambled (at high temperature)	1.2	6.09 ± 0.13	0
Scrambled (at low/moderate temperature)	3.1	5.9 ± 0.1	<1

[a]Includes results from experiments with SE PT4 and *S.* Typhimurium PT110 and PT141.
[b]Eggs fried in vegetable oil at approximately 120°C until white appeared solid and opaque. Sunny-side-up eggs were cooked approximately 1.5 to 2 minutes. Over-easy eggs were cooked for up to 1 minute longer.
Source: Humphrey et al.[11]

Subtracting the mean log_{10} cfu/gm of survivors from the mean cfu/gm of inoculum results in the log_{10} reduction (Table 3-25). More effective cooking methods, such as frying over easy and scrambling, did not have sufficient bacteria surviving to allow enumeration. Humphrey et al.[11] state that their detection limit was about 1 log_{10} cfu/gm. For the trials that did not allow enumeration but still resulted in recovery of bacteria, a 1 log_{10} cfu/gm was assigned. If no bacteria were recovered, a log_{10} reduction equivalent to the starting log_{10} cfu/gm of bacteria was assumed. Table 3-25 shows the log_{10} reduction for each cooking method. The results were weighted to account for those trials resulting in 0 or 10 cfu/gm. This resulted in an "effective log_{10} reduction". Finally, each of these log_{10} reductions was assigned to a fraction of all egg dishes.[12]

Only 86% of total egg dishes are accounted for in Table 3-25. The other 14% of egg dishes are reportedly hard-boiled eggs.[12] Humphrey et al.[11] state that the maximum effectiveness of cooking observed after boiling eggs for 10 minutes was about an 8-log_{10} reduction. Hard-boiled eggs were assigned an effective log_{10} reduction of 8.

TABLE 3-25 DETERMINING LOG_{10} REDUCTIONS FOR COOKING TYPES.

Starting Log_{10}	Ending Log_{10}	Percent Samples with Surviving Bacteria	Log_{10} Reduction	Effective Log_{10} Reduction	Fraction of Egg Dishes[12]	Comments
6.81	5.87	100%	0.94	0.94	0.12	Soft boiled and poached
6.9	5.14	100%	1.76	1.76	0.135	Sunny side up
6.88	1	56%	5.88	6.32	0.135	and over easy reported as 27%
6.09	0	0%	6.09	6.09	0.235	All scrambled and
5.9	1	97%	4.9	4.93	0.235	omelets reported as 47%

The frequency distribution for fraction of egg dishes ordered by the effective $\log_{10}$ reduction is shown in Table 3-26.

TABLE 3-26 FREQUENCY OF EFFECTIVE LOG_{10} REDUCTIONS.

Type of Dish	Effective Log_{10} Reduction	Frequency
Soft boiled and poached	0.9	0.120
Sunny side up	1.8	0.135
Scrambled and omelets	4.9	0.235
Scrambled and omelets	6.1	0.235
Over easy	6.3	0.135
Hard boiled	8.0	0.140

Three cumulative frequency distributions for effective $\log_{10}$ reduction are shown in Figure 3-24. The curves were fit to the data points using a least-squares fitting algorithm. None of them provides a compelling visual fit. Consequently, this distribution is modeled as a discrete distribution using the data in Table 3-26.

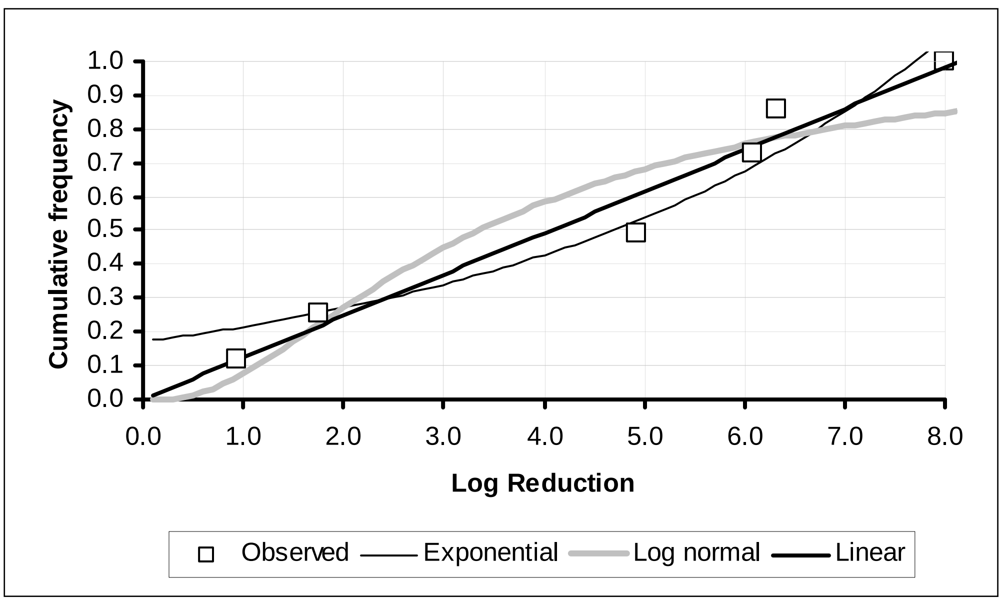

FIGURE 3-24 CUMULATIVE FREQUENCIES OF EFFECTIVE LOG_{10} REDUCTION DUE TO COOKING.

To model cooking, three types of meals are considered. The consumption analysis in Annex H categorizes eggs as those served as main meals, in beverages, or as ingredients in mixtures. Additionally, that analysis further categorizes these servings as potentially higher risk or lower risk. Higher risk products are those likely to experience very limited cooking before consumption. Lower risk products are likely to be thoroughly cooked. Table 3-27 summarizes the fraction of product in each of these categories.

TABLE 3-27 FREQUENCIES OF DIFFERENT EGG SERVING TYPES.

Type of Egg Consumption	Relative Risk	% of Shell Eggs
	Lower risk	0.08%
Main meal	Higher risk	44.76%
	Lower risk	0.00%
Beverage	Higher risk	0.33%
	Lower risk	53.04%
Ingredient	Higher risk	1.79%

All eggs served as a main meal or used as ingredients in higher risk meals are assumed to have the same distribution of $\log_{10}$ reductions as those described above. All beverages are assumed to experience a 0-$\log_{10}$ reduction, and all lower risk servings of eggs as ingredients in mixtures are assumed to experience a 12-$\log_{10}$ reduction.

Servings per egg, V

Once an egg is used to prepare a meal, the bacteria remaining after cooking will be consumed. The number of individuals exposed to the bacteria in that egg is determined from the servings per egg, *V*. This value both serves to estimate the number of exposures that result from an egg containing *Salmonella* and estimates the actual dose of bacteria consumed per serving. If there are multiple servings consumed from a meal containing a contaminated egg, then these multiple servings increase the number of persons exposed but reduce the dose consumed by any one person.

The number of servings to which an egg contributes is best described using a probability distribution. This section presents the data and analysis for estimating this distribution. A single egg may feed one person or many persons. This is because eggs may be combined with other eggs to produce more than one serving. The Continuing Survey of Food Intake by Individuals (CSFII) estimates the grams of shell egg in products made from shell eggs, but it does not detail how many eggs were incorporated into individual servings.

The CSFII does, however, contain some useful information to help construct a probability distribution to represent the number of servings per egg. Lin (1997) reports that when eggs are served as a main meal that 12% were soft boiled or poached, 27% were served sunny side up or over easy, and 14% were served hard boiled. Thus 53% of the eggs served as main meals were likely to have served just one person. If the remaining 47% of eggs were served scrambled or in omelets, then assume half of those (23.5%) also served just one person. Thus 76.5% of shells eggs served as a main meal are assumed to have served one person.

The preceding discussion estimates the frequency of eggs used as a main meal that are eaten by one person. However, what percentage of all eggs is used as a main meal? To estimate this value the tables for consumption of shell eggs in Annex H are used. The number of eating occasions in 2 days was multiplied by the average weight of egg per serving for each category. Table 3-28 shows the percentage of total shell eggs that are consumed in main meals, in beverages, or as ingredients in a mixture. Thus, 44.9% of all eggs are used as the main meal, and 76.5% of them go to a single person. Hence, 34.3% of all eggs consumed in the home are a main meal served to only one person.

TABLE 3-28 PERCENTAGE OF SHELL EGGS IN DIFFERENT MEAL TYPES.

Type of Egg Consumption	% of Shell Eggs
Main meal	44.9
Beverage	0.3
Ingredient	54.8

When eggs are served as an ingredient in a mixture (i.e. 54.8% of all eggs), approximately 10% of the servings have a serving size of less than 1 gram. A single egg then can contribute to about 58 servings on average. The fraction of shell eggs that contribute to 58 servings is then given by 0.10 x 0.548 / 58 or approximately 0.1%. Thus, a reasonable probability distribution for the number of servings per egg among all types of servings would include among its data points 34.3% of eggs serving just one person and about 0.1% of eggs serving 58 or more persons.

A Poisson distribution did not have a sufficient variance to model the variability in the number of servings per egg. An approximation to a lognormal distribution was used to ensure a sufficient variance. Excel Solver was used to estimate parameters for a lognormal distribution with the constraints described above. Figure 3-25 shows the subsequent distribution with a mean of 1.6 servings and a standard deviation of 3.2. The return from this lognormal distribution was rounded to the nearest integer. Any values returned that were less than one, were set to 1.

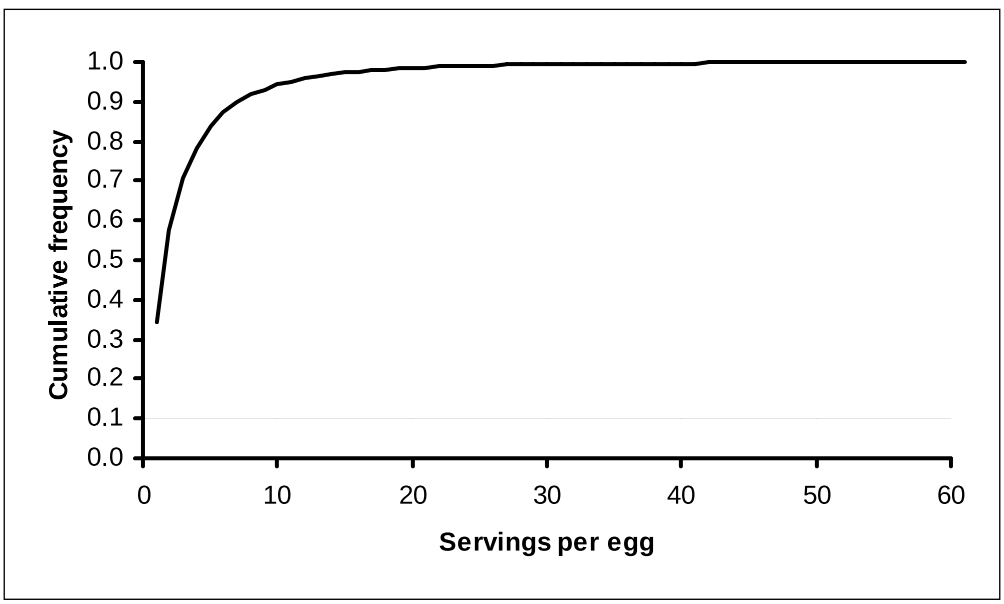

FIGURE 3-25 MODELED DISTRIBUTION OF SERVINGS PER EGG.

The bacteria remaining in an egg after cooking are divided in the model by a random selection from the distribution for *V* (Figure 3-25) to determine the dose of bacteria per egg serving. The dose estimated here is the argument for the dose-response relationship (chapter 4).

Exposure Assessment Results: SE in Shell Eggs

The model was run with 50,000 iterations, requiring 2.5 hours on a Pentium IV 1500 MHz computer. Results are summarized with reference to the conceptual model in Figure 3-26.

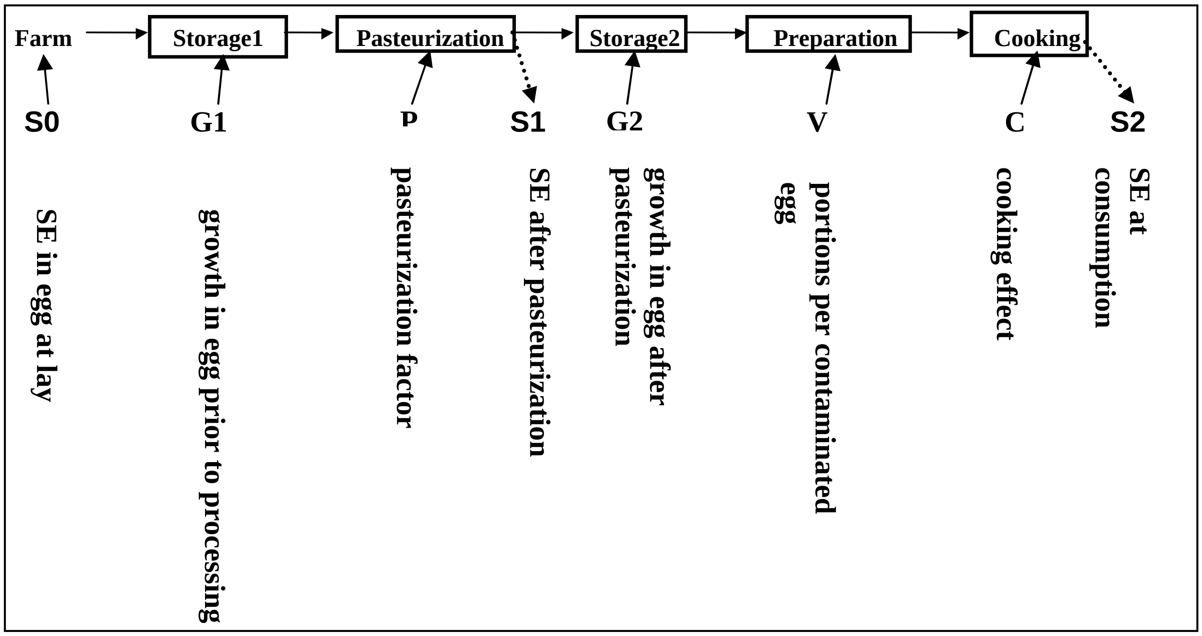

FIGURE 3-26 FLOW OF PRODUCT IN EXPOSURE ASSESSMENT.

SE per egg at lay, S_0

Figure 3-27 shows the number of bacteria in an egg at lay given that the egg is SE contaminated.

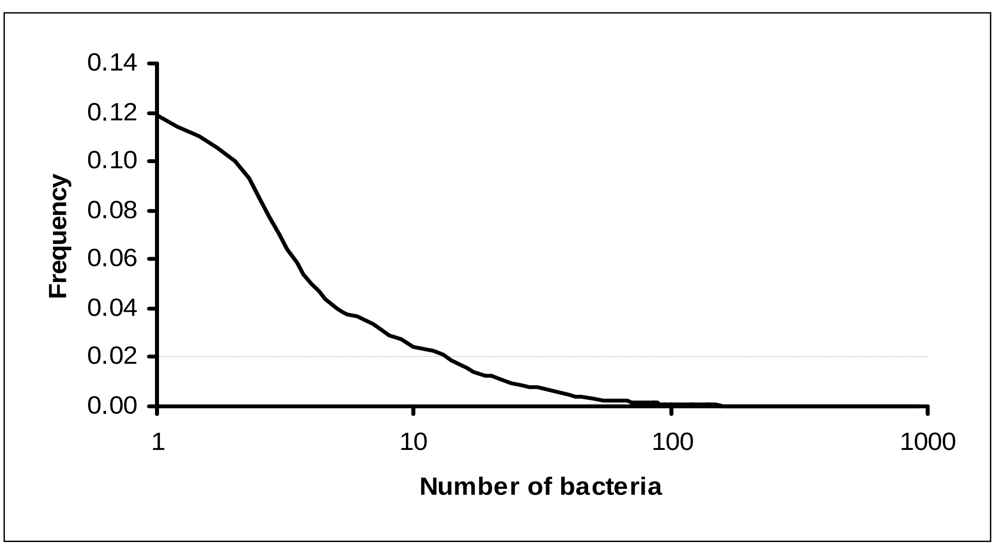

FIGURE 3-27 BACTERIA IN SE-CONTAMINATED EGGS AT TIME OF LAY.

The likelihood that an egg is SE contaminated is simulated using the inputs from Table 3-1 and has an expected value of about 0.00028 or approximately 1 in every 3,600 eggs. Thus, the frequency distribution shown in Figure 3-27 applies to only one out of every 3,600 eggs.

Growth effect before processing, G_1

About half of all contaminated eggs simulated experienced SE growth ($G_1 > 1$) before processing; about 15% of all contaminated eggs experienced more than 1 $\log_{10}$ of SE growth ($G_1 > 10$). Figure 3-28 shows the frequency distribution for G_1. Figure 3-29 shows the same information as in Figure 3-28 but with the graph rescaled and plotted as a cumulative frequency.

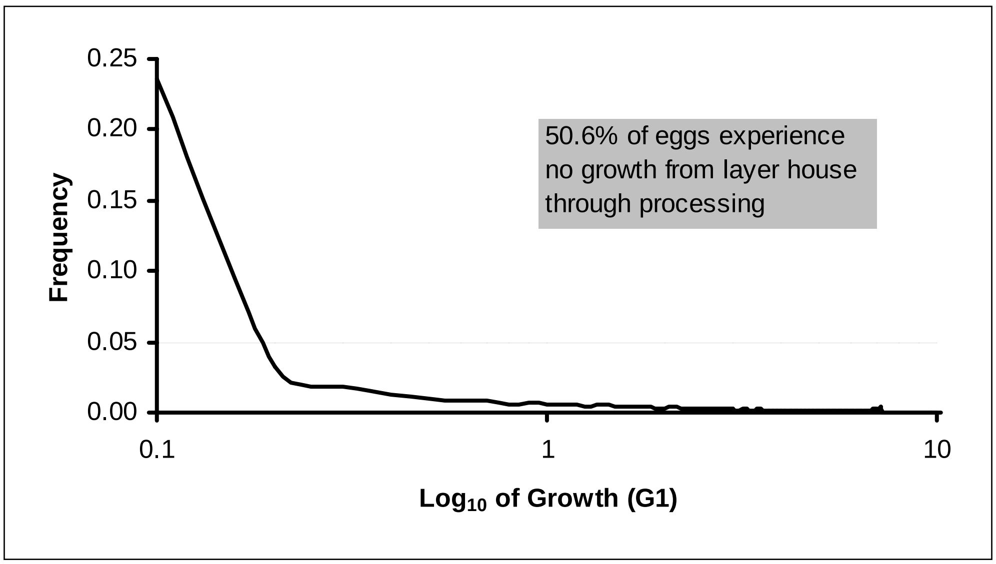

FIGURE 3-28 LOG_{10} GROWTH IN SE-CONTAMINATED EGGS BEFORE PROCESSING.

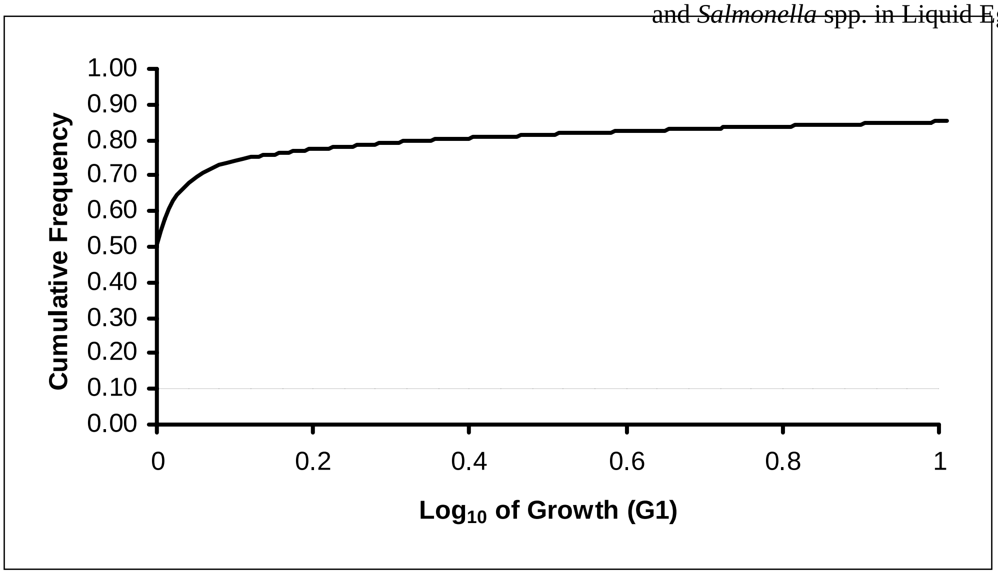

FIGURE 3-29 CUMULATIVE FREQUENCY OF LOG_{10} GROWTH IN SE- CONTAMINATED EGGS BEFORE PROCESSING.

Percentage of bacteria that survive pasteurization, P

As noted earlier, one purpose of this risk assessment is to support the determination of a required level of effectiveness from pasteurization, and establishing the regulatory standard value of P is a risk management task and is not a focus of this risk assessment. To support the establishment of a performance standard, however, this risk assessment estimates the percentage of bacteria expected to survive different levels of pasteurization and from those estimates determines the resulting risk of human illness. The effect of this mitigation is given in terms of human illness in chapter 5.

Growth effect after processing, G_2

The amount of SE growth after processing is less than that before processing probably because of lower storage temperatures following processing of eggs. Although about half of contaminated eggs experience any SE growth (G_1 > 1) before processing, only about 4% of contaminated eggs experience more than 1 log_{10} of SE growth (G_2 > 10). Figure 3-30 shows the frequency distribution for G_2. Figure 3-31 is a rescaling of the information in Figure 3-29.

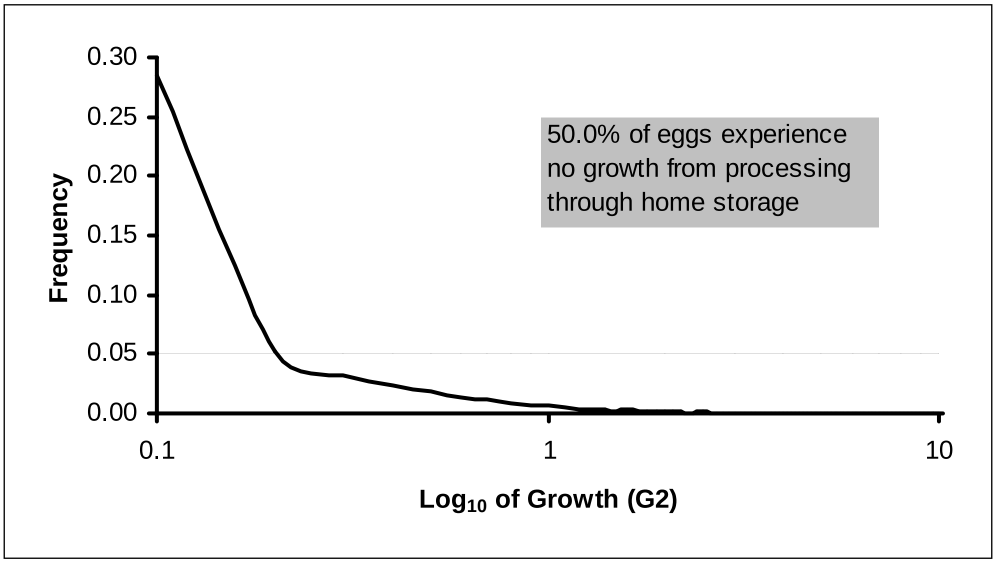

FIGURE 3-30 LOG$_{10}$ GROWTH IN SE-CONTAMINATED EGGS AFTER PROCESSING.

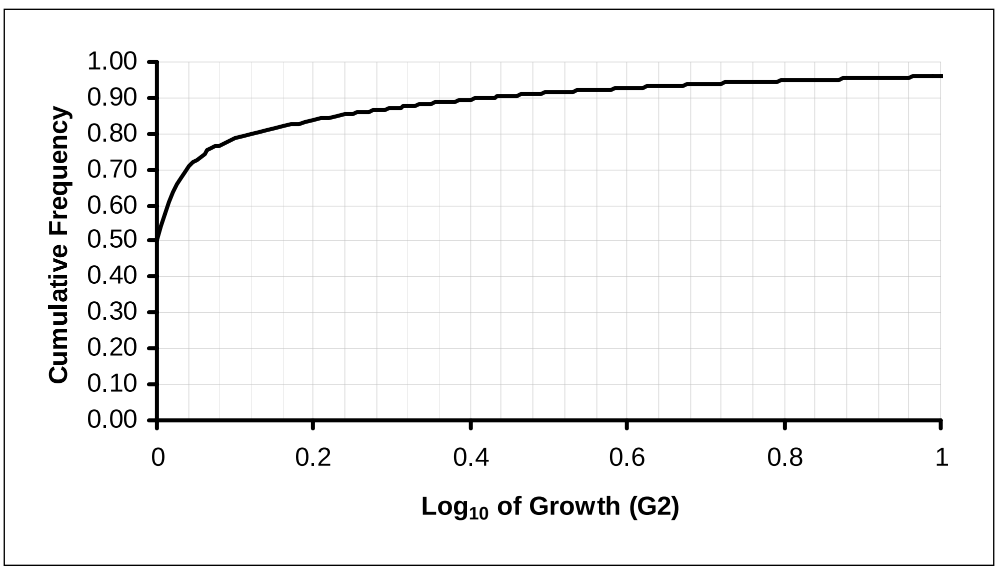

FIGURE 3-31 CUMULATIVE FREQUENCY OF LOG$_{10}$ GROWTH IN SE-CONTAMINATED EGGS AFTER PROCESSING.

***Percentage of bacteria surviving cooking,* C**

Because the effect of cooking is governed by a discrete distribution, the log$_{10}$ reductions due to cooking reflect the discrete values of the input distribution. Figure 3-32 shows the modeled log$_{10}$ reductions due to cooking. Note that the x-axis values are given in terms of log$_{10}$ reduction for simplicity. To convert these to values for *C* in the conceptual model, the anti-log of each value is taken. In other words, 52.7% of eggs have the contamination multiplied by 10^{-12} (a 12-$\log_{10}$ reduction) prior to consumption.

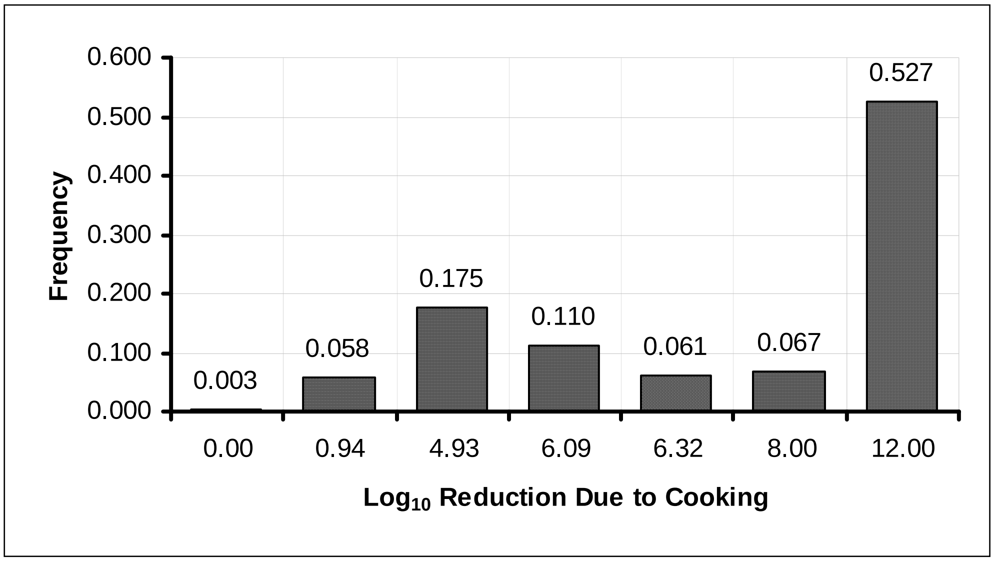

FIGURE 3-32 LOG_{10} REDUCTIONS DUE TO COOKING FOR CONTAMINATED EGGS.

Cooking is an important mitigation that will decrease the number of SE by 12 $\log_{10}$ (10^{-12}) in over half of the contaminated eggs. This degree of cooking is associated in the model with thorough heating of mixtures incorporating shell eggs as ingredients. Less thorough cooking methods are applied to eggs served as main meals but this cooking could still eliminate moderate amounts of bacterial contamination.

Number of SE per consumed serving

The fundamental output of the exposure assessment is the number of SE per contaminated serving consumed. The model predicts that approximately 85.6% of eggs that were originally contaminated with SE would produce servings that had no SE in them after storage and cooking. Figure 3-33 shows the number of SE expected in servings made from originally contaminated eggs.

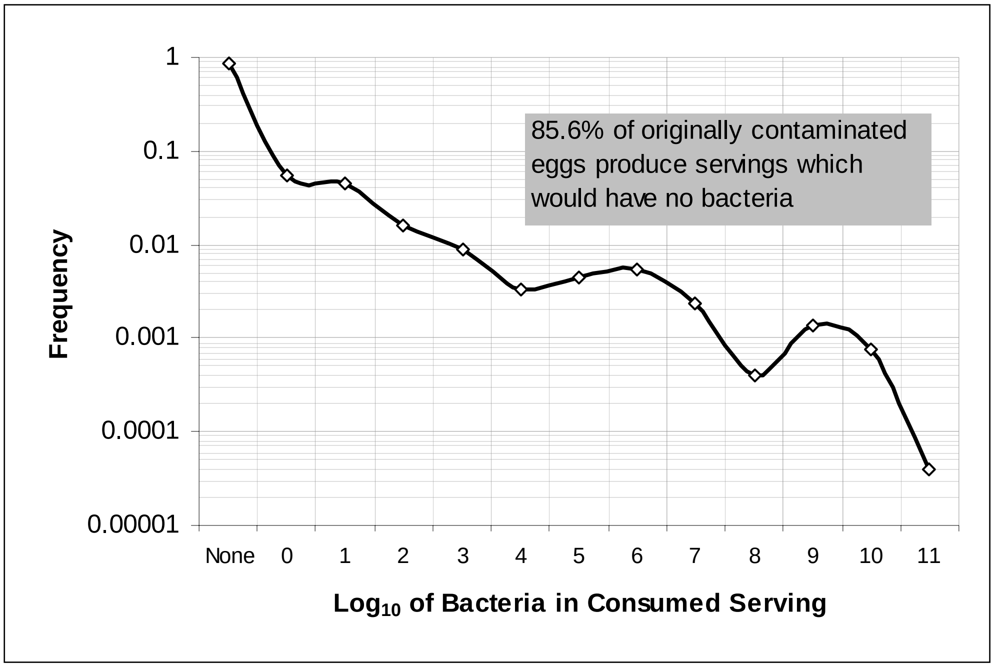

FIGURE 3-33 SE PER CONSUMED SERVING MADE FROM CONTAMINATED EGGS.

Figure 3-34 shows the same information as Figure 3-33 but in a non-log scale, emphasizing the low numbers of SE in eggs in consumed servings from eggs that were originally contaminated.

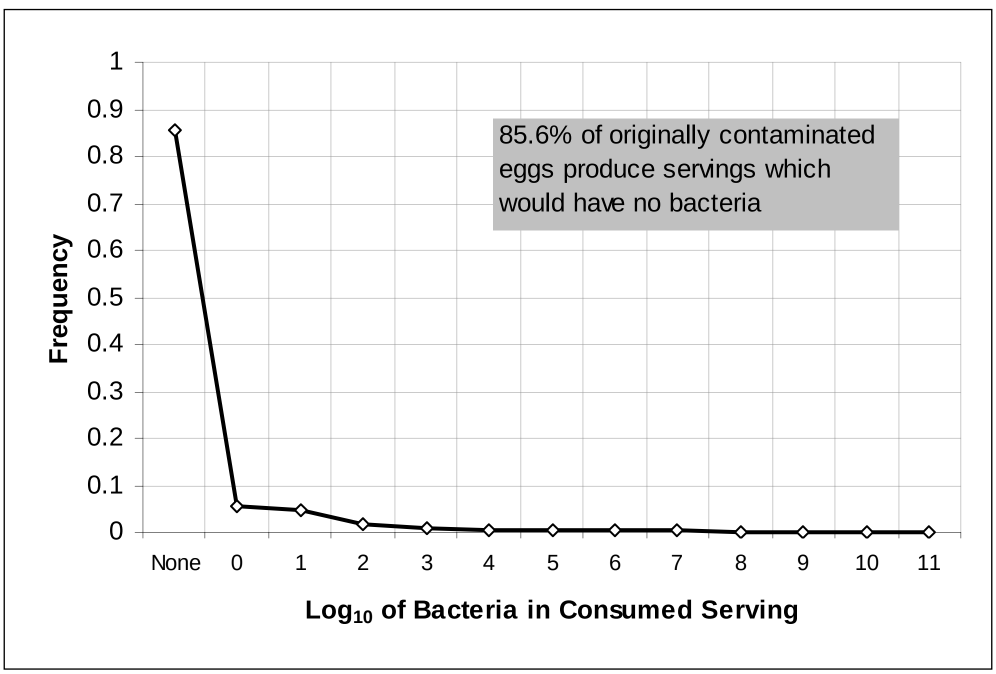

FIGURE 3-34 SE PER CONSUMED SERVING MADE FROM CONTAMINATED EGGS ON NON-LOG SCALE.

Additional exposure assessment results

The following steps were specifically modeled for each egg in the exposure assessment results summarized above:

- laying house
- on-farm storage (off-line only)
- transportation to the processor (off-line only)
- pre-processing storage
- post-processing storage
- retail transportation or transportation to a distributor
- retail storage or storage at a distributor
- home transportation or transportation to a hotel, restaurant, or institution
- home storage or storage at a hotel, restaurant, or institution.

Figure 3-35 and Figure 3-36 show the median age of eggs, median temperature of eggs, and median bacteria in contaminated eggs, respectively, for each of the steps listed above. Additionally, the figures all present the 5^{th} and 95^{th} percentiles for each parameter. Although pasteurization is shown as a step in these charts, the effect of pasteurization is not shown until mitigations are applied in chapter 5. Note that these charts do not include the effect of cooking just prior to consumption. Figure 3-35 shows that the median egg would reach retail facilities within a week and would be consumed within 3 weeks.

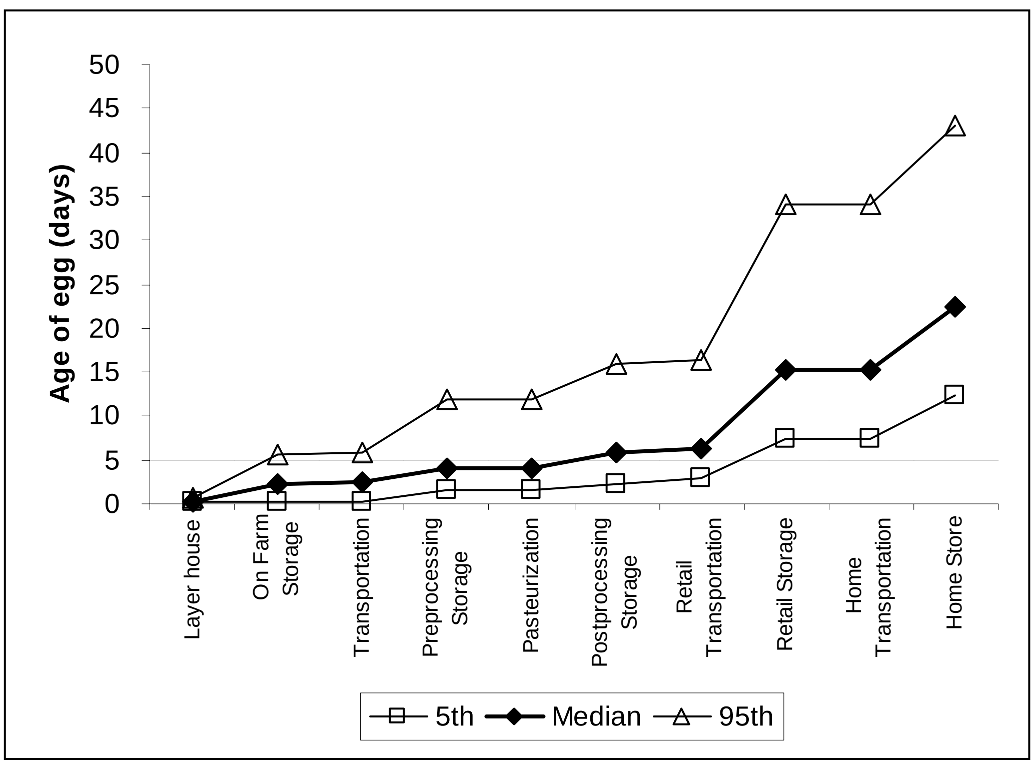

FIGURE 3-35 AGE OF EGGS AT DIFFERENT MODEL STEPS.

FIGURE 3-36 shows the temperature of eggs at each of the different model steps. Note that the times that correspond with the longest median storage times (retail and home) also correspond with the lowest median storage temperatures. Home transportation shows a marked increase in egg temperature, but this is generally for a very short time (no more than 6 hours in the model). Thus, steps after processing would be expected to have less effect on bacterial numbers than steps before processing.

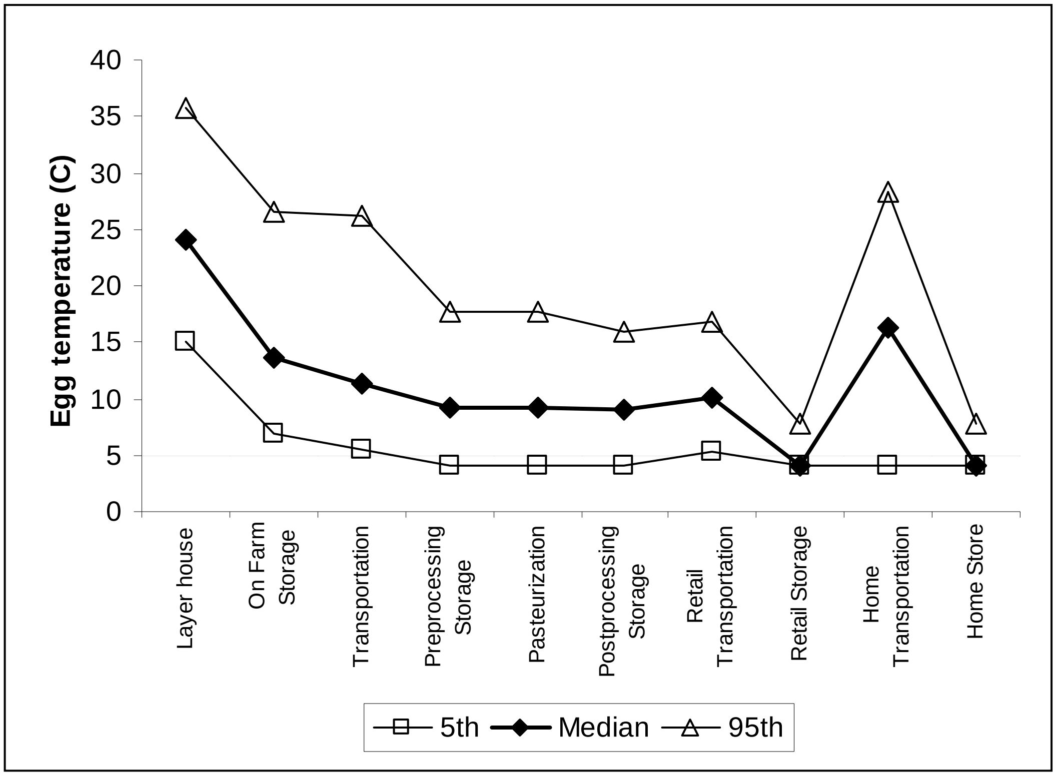

FIGURE 3-36 TEMPERATURE OF EGGS AT DIFFERENT MODEL STEPS.

The amount of growth that takes place appears to be driven more by the temperature of storage rather than the time of storage. At the 95th percentile, the longest storage time depicted in Figure 3-35 is for retail storage. The 95th percentile for the number of bacteria per contaminated egg (Figure 3-37) shows relatively little growth during this step. On the other hand, the greatest amount of bacterial growth appears to be during on-farm storage and pre-processing storage. Figure 3-37 shows the number of SE expected at each model step. The median number of bacteria raises only slightly throughout the various storage steps. The 95th percentile, however, rises much more quickly. This effect for the top 5% of the eggs is most noticeable in the step just before processing, although it is evident in all steps. This implies that some storage conditions allow for rapid growth for a small percentage of eggs. SE-contaminated eggs are infrequent, but when they do occur in our simulations they generally contain less than 100 organisms at the time of lay. Most of these contaminated eggs will undergo little or no growth from lay through processing. Furthermore, most of these eggs undergo little or no growth all the way through home storage. However, the variability about the median number of bacteria increases over the various steps. Thus, the 95th percentile of bacteria per egg is only about 100 at the end of layer house storage, while it is over 10,000,000 at the end of home storage.

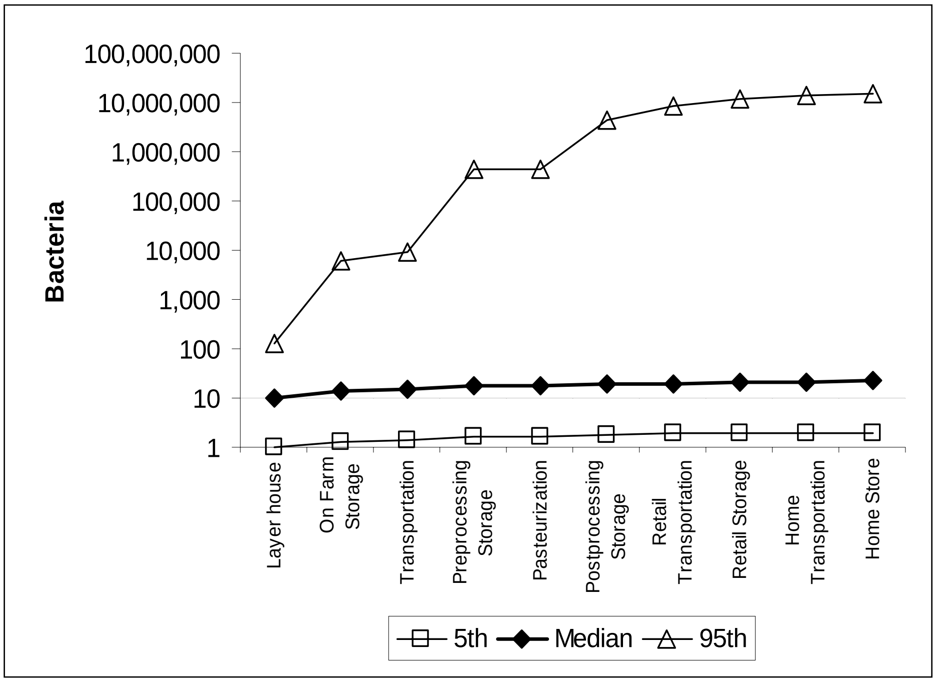

FIGURE 3-37 NUMBER OF SE IN CONTAMINATED EGGS AT DIFFERENT MODEL STEPS.