3 Methodology

This section has four parts. Section 3.1 describes the simulation model developed as part of this analysis to quantify the impact of introducing BSE into the U.S. cattle population on both animal health and on potential human exposure to contaminated food products. The description of the model in Section 3.1 reflects assumptions that are part of our "base case" scenario. This scenario represents the present state of the U.S. cattle population, along with government regulations and prevailing agricultural practices. Section 3.2 describes the uncertainty analyses (also referred to as a sensitivity analysis) conducted to determine how changing various assumptions influences the model's predictions. Section 3.3 describes how we used the model, with its base case assumptions, to evaluate the impact of alternative sources of infectivity on the U.S. given current conditions. These sources include spontaneous BSE, importation of from 1 to 500 BSE-infected cattle, domestic scrapie, chronic wasting disease, TSEs in domestic mink, pigs, and chickens, and recycled food waste. Finally, Section 3.4 evaluates alternative scenarios, including Switzerland during the period when it is thought that country first imported BSE-infected animals. That evaluation, which compares empirically reported clinical BSE cases in Switzerland during the period 1985 to 2001 to the corresponding number of clinical cases predicted by the model, serves as an indicator of the model's plausibility. Section 3.4 also describes our methodology for evaluating the possibility of spontaneous BSE in the U.S. prior to the 1997 feed ban, the impact of importing infected cattle from the UK during the 1980s, and the implementation of various risk management strategies in the U.S.

3.1 Simulation Model and Base Case Assumptions

The simulation model can be thought of as consisting of four components, as illustrated in Figure 3-1. The first component (Section 3.1.1) characterizes the lifecycle of cattle in the US, quantifies the potential infection of animals at different points during this cycle, and characterizes their ultimate disposition (slaughter, death due to natural causes followed by either disposal or rendering, and death due to BSE infection followed by either disposal or rendering). The second component of the model (Section 3.1.2) describes how animals sent to slaughter are processed. Tissue may be disposed of, sent to rendering, or prepared for potential human consumption. The third component of the model (Section 3.1.3) characterizes the disposition of material sent to rendering. That material may exit the system (*e.g.*, because it will be disposed of, exported, or used to produce feed for animals other than cattle) or end up in feed that is administered to cattle.

The final component of the model (Section 3.1.4) quantifies infectivity in material presented for human consumption.

3.1.1 Cattle Population Dynamics

Figure 3-2 further details the cattle population dynamics component of the simulation model. In particular, this component describes the rate at which cattle are born, the rate at which animals are slaughtered, and the rate at which they die of other causes. Cattle can become infected when they are born as a result of maternal transmission. Alternatively, they can be born uninfected but become infected later as a result of exposure to BSE-contaminated feed. Infected animals may proceed to the clinical stage of the disease. Alternatively, they may be slaughtered, or die of other causes. Likewise, animals displaying clinical signs may also be slaughtered or die of other causes, including BSE. Section 3.3 details the different ways in which BSE infectivity could be introduced to the U.S. cattle population.

The model includes a detailed characterization of the cattle population dynamics because many of the rates influencing disease prevalence depend on animal age, type, and gender. Rates depending on at least some of these factors include the rate at which healthy animals become infected due to consumption of contaminated feed (this dependence stems from the influence of age, type and gender on the amount of meat and bone meal (MBM) animals consume, and the influence of age on susceptibility to infection given a specified exposure), the rate at which animals are slaughtered, and the rate at which animals die of causes other than slaughter.

The remainder of this section summarizes the following base case assumptions: 1) the number of animals in the U.S. cattle population by age, gender, and type (*i.e.*, dairy or beef, destined for production or breeding), their birth rate, slaughter rate, and rate of death from other causes; 2) cattle consumption of bypass protein and blood meal by age, type, and gender; 3) the dose-response relationship for cattle orally exposed to BSE and the influence of age on this relationship; 4) the rate at which infected cows transmit BSE to their offspring; and 5) the incubation period for BSE (*i.e.*, the time between infection and when clinical signs become apparent) and the time until death following the development of clinical signs.

3.1.1.1 Size of Cattle Population, Birth Rates, Slaughter Rates, and Rates of Death due to Other Causes

The simulation developed for this analysis requires specification of the number of animals by age in months for each gender within each of three animal classes: dairy, beef, and beef reproductive animals. This last group represents those beef cattle that live beyond the age of 24 months for the purpose of providing beef calves. Base case values for the cattle population size appear in parameter <initsize> of the parameter group genesisVisitor (see Appendix 1).

Developing this information was complicated by the fact that available data sources do not break down the age distribution in sufficient detail, and in some cases, combine groups that must be characterized separately for the simulation. For example, statistics published by the FSIS Animal Disposition Reporting System (ADRS) (USDA-FSIS, 1998) report the slaughter rate for dairy and beef cows combined, rather than breaking out the slaughter rate for each group separately. The development of this information has been further complicated by the fact that some of the reported statistics do not appear to be consistent with each other. For example, as explained below, the reported number of steers and heifers slaughtered is consistent with birth rates that imply a total cattle population of 140 million, rather than the true value of approximately 100 million. When forced to diverge from reported statistics for the purpose of maintaining internal consistency, we do so in ways that minimize the impact of distortions on the validity of the simulation results. In the example described in this paragraph, our inflation of the U.S. cattle population should have a minimal impact on simulation results because the rate at which BSE spreads does not in general depend on this statistic[3].

Population size

The specific population values for each age/type/gender category were computed using spreadsheet software and the birth, death, and slaughter rates described in this section. The documentation in Appendix 1 (parameter group genesisVisitor, parameter <initSize>) describes these computations. However, although the simulations used these values to specify an initial population distribution, the model altered these values to reflect the simulated impact of birth, death, and slaughter. As a result of these influences, the initial population of approximately 140

[3] The possibility of spontaneous development of BSE is the one exception to this generalization because its rate is proportional to the size of the population. By overstating the size of the population, we have therefore overstated the potential impact of spontaneous disease, should it exist (See 5.1.2.5.)

million decreases to and stabilizes at approximately 130 million during execution of the simulation. As noted above, this change has a very limited impact on the simulation results.

Slaughter Rate

Animals are removed from the herd for slaughter at different rates depending on age, type and gender. The base case assumptions for the slaughter rates are based on statistics recorded by USDA and are detailed in Table <rateSlaughter> of the rateSlaughter file (see Appendix 1).

Death Rate for Reasons Other Than Slaughter

The so-called "natural death rate" may be potentially important because some fraction of these animals, also referred to as animals that die on the farm, are sent to rendering. Animals that die on the farm due to BSE infection have the maximum level of infectivity and therefore introduce the possibility that a substantial amount of BSE contamination could enter the rendering system. The base case assumes that animals with BSE will live only 2 to 6 months after reaching the clinical stage of the disease. The natural death rates assumed by the base case appear in Table <probDeath> in file deathVisitor (see Appendix 1).

Birth rate assumptions

The base case assumes that female cattle can calve between the ages of 24 and 180 months. During that time, they produce a calf once every 12 months on average. Documentation accompanying the birthVisitor file (see Appendix 1) explains the basis for these assumptions.

3.1.1.2 Cattle Consumption of Bypass protein and Blood Meal

MBM is one supplement for livestock feed, although in the U.S., other sources are also used, especially vegetable protein derived primarily from soybeans. The primary hypothesis for the spread of BSE in the UK is that infectious materials was recycled through the rendering and feed production processes resulting in the subsequent exposure of cattle. The amount of bypass protein-supplemented feed consumed by an animal, and hence its potential exposure to MBM, depends on the animal's age, type, and gender. Dairy cows receive the greatest amounts of supplemental bypass protein. Because the base case assumes that there may be breaches of the

FDA feed ban (Section 3.1.3), some exposure can occur as the result of exposure to feed if BSE is present in the U.S. The <consumption> table in files proteinInfector and bloodInfector respectively detail our assumptions for cattle consumption of bypass protein and blood meal.

3.1.1.3 BSE Dose-Response

The dose-response function for BSE quantifies the probability that an exposed animal will become infected with BSE as the result of ingesting contaminated materials. The exposure is quantified in terms of the number of susceptibility-adjusted ID_{50}s ingested. The susceptibility-adjusted ID_{50} exposure equals the product of an age-specific susceptibility factor and the number of unadjusted ID_{50}s ingested. The base case assumes that the dose response is linear up to an exposure level of 2.0 adjusted ID_{50}s, with an infection probability of zero at an exposure level of zero, and an infection probability of 1.0 at an exposure level of 2.0 adjusted ID_{50}s. For example, an animal that ingests 1.0 susceptibility-adjusted ID_{50}s has a 50% chance of becoming infected. Note that an animal that ingests more than 2.0 adjusted ID_{50}s has a 100% chance of becoming infected. Figure 3-3 illustrates the straight-line dose-response relationship assumed as part of the base case, along with a hypothetical alternative sigmoidal dose-response relationship.

Our relationship between susceptibility and age (see Figure 3-4) is based on the assumption that susceptibility peaks at age four months and that it declines exponentially thereafter at a rate of 85% per year, leveling off at approximately 10% of its peak value (Koeijer et al., In press). Table <susceptibility> in file proteinInfector (see Appendix 1) details this relationship. Section 2 provides further background on susceptibility.

3.1.1.4 Maternal Transmission

Although there is no direct evidence of BSE transmission from cow to calf, it is assumed to have occurred when a calf born to a cow incubating BSE contracts the disease in the absence of any other known sources of BSE exposure. Section 2.2.1 reviews evidence of maternal transmission for other TSEs, with the best evidence from scrapie (Kimberlin, 1990, Foster et al., 1992, Elsen et al., 1999), and for BSE (Wilesmith et al., 1997, Ferguson et al., 1997b, Donnelly et al., 1997a, Donnelly et al., 1997b, Donnelly, 1998). The base case assumes calves born to infected cows during the last one-sixth of the incubation period will become infected with 10% probability. Text accompanying table <maternalContagiousPoint> in file sickBovine and table

<probTrans> in file birthVisitor (see Appendix 1) further documents the basis for these two parameter values.

3.1.1.5 The BSE Incubation Period, and Time Until Death Caused by BSE

The base case assumes that the duration between infection and manifestation of clinical signs follows a distribution described inferred by Ferguson et al. (1997) (Ferguson et al., 1997a) from data collected in the UK. The density is right-skewed with a median of approximately four years. The 5th percentile is approximately 2.5 years, the median is approximately four years, and the 95th percentile is approximately seven years. Table <clinicalDate> in file sickBovine (see Appendix 1) further details this distribution.

The base case assumes that the time between the manifestation of clinical signs and death is uniformly distributed between 2 and 6 months (Dagmar Heim, Personal Communication). Table <clinicalDuration> in file sickBovine (see Appendix 1) documents this assumption.

3.1.2 The Slaughter Process

If an animal with BSE is slaughtered, some practices can contaminate tissues destined for potential human consumption with BSE infectivity. In addition, many tissues not used for human consumption go to rendering and may become available to infect other bovines (Section 3.1.3). This section describes the base case assumptions for the slaughter process (Figure 3-5). It also describes ways in which infectivity can be diverted from uses that may result in either human or bovine exposure.

3.1.2.1 Level of Infectivity and Distribution of Infectivity Throughout the Carcass

The amount of infectivity that becomes available for human consumption or ends up being recycled into cattle feed depends in part on the total amount of infectivity in a slaughtered animal and how that infectivity is distributed through its carcass. Our model assumes these factors depend on the amount of time that has passed since the slaughtered animal became infected. Tables <organDistribution> and <totalInfectivity> in file materializer (see Appendix 1) details our base case assumptions.

Our description of the distribution of infectivity among the tissues of an infected animal is based on the pathogenesis experiment (Wells et al., 1998, Wells et al., 1999), as interpreted by SEAC (February, 1998). This experiment measured the infectivity in each of 44 tissues and fluids following experimental infection of cows with BSE. The experiment found infectivity in the small intestine from months 6 to 18 months post infection, with no detectable infectivity in any other tissues. At the end stage of disease, ($\geq$ 32 months post infection), infectivity was found in the brain, spinal cord, dorsal root ganglia (DRG), trigeminal ganglia (TGG), and again in the small intestine. We assume that findings of infectivity in bone marrow at one time point were spurious, although we do investigate the potential for the disease to directly infect blood (so-called "inherent infectivity") (Section 3.2.6). Table 3-1 details our specific assumptions.

Note that these assumptions are based on an assumed incubation period of 36 months (as observed in the pathogenesis study). For animals with incubation periods of durations other than 36 months, the time periods post inoculation are scaled accordingly. For example, for an animal with an incubation period of 72 months, there is no infectivity in the brain prior to month 64 (*i.e.*, $32 \times 72 / 36$).

Table 3-1
Relative Infectivity of Specific Tissues Specified From an Infected Bovine (Based on (SSC, 1999a))[a]

Tissue	Fraction of Total Infectivity
Brain	No infectivity in cattle < 32 months post-inoculation (PI) 32 months PI and over: 64.1%
Trigeminal Ganglia	No infectivity in cattle < 32 months post-inoculation. 32 months PI and over: 2.6%
Other Head (eyes, *etc.*)	No infectivity in cattle < 32 months post-inoculation. 32 months PI and over: 0.04%
Distal Ileum	6-18 months post inoculation: 100% 18-31: No Infectivity 32 months PI and over 3.3%
Spinal Cord	No infectivity in cattle < 32 months post-inoculation. 32 months PI and over: 25.6% infectivity
Dorsal Root Ganglia	No infectivity in cattle < 32 months post-inoculation. 32 months PI and over: 3.8 % infectivity

Notes:

a. The post-inoculation time values in this table reflect the assumption that the incubation period is 36 months. See text for explanation.

The base case assumes that the total quantity of infectivity in an animal with BSE reaches its maximum level when the animal develops clinically detectable signs (*i.e.*, becomes "clinical") (see Section 3.1.1.5 for a discussion of the incubation period duration). Prior to that time, the total level of infectivity follows the pattern illustrated in Figure 3-6. In this example, the animal develops clinical signs 36 months after infection. During the first five months of infection, total infectivity in the animal is around 0.1% of its maximum value, followed by an increase to around 2.5% of its maximum value between months 6 and 18 post infection. Up until this point, all infectivity is assumed to be in the gut. Starting in month 19, infectivity is assumed to be distributed among several tissues, with the bulk in the brain and the spinal cord, and the remainder divided among the gut, DRG, eyes, and TGG. At this time, total infectivity drops to zero but and then grows exponentially until it reaches its maximum level in month 36. For incubation periods other than 36 months, the model scales the horizontal (time) axis in Figure 3-6 proportionally. The total amount of infectivity in an animal with clinical BSE is assumed to

10,000 cattle oral ID_{50}s (SSC, 1999a, SEAC, 2000, Gale and Stanfield, 2001). Note that this value has not been adjusted to reflect age-specific susceptibility (see Section 3.1.1.3).

3.1.2.2 *Antemortem* Inspection

Once the animal is at the slaughter facility, it is inspected for signs of disease. FSIS regulations require that for certain diseases the whole animal is condemned at *antemortem* (AM) inspection (USDA-FSIS, 1997). Condemned animals can be rendered or incinerated.

Animals not showing clinical signs at AM inspection are not likely to be condemned for BSE but could be condemned if they show signs of other diseases. The condemnation rates for animals not showing clinical BSE signs depend on age and gender. The rates used in the base case are based on data collected by FSIS for the year 1998 (see Table 3-2). In particular, the base case assumes that the AM condemnation rate is approximately 1% for animals less than one year of age, 0.01% for animals between the ages of one year and 31 months, and 0.2% for animals older than 31 months of age.

Table 3-2
Cattle Slaughtered and Condemned (1998)[a]

Cattle age group	Total Animals slaughtered	Total Animals Condemned	Probability not pass AM	Animals Condemned Postmortem	Probability that will not pass Postmortem
< 12 months	1,483,430	14859	0.0098	13,799	0.0092
12 to 24 months	32,690,003	2,349	0.0001	22,697	0.0007
≥ 24 months	7,815,074	21,906	0.0028	11,0172	0.0139

Notes:

a. From USDA: Animal Disposition Reporting System

Animals that are condemned following AM inspection are usually rendered, although a small proportion are incinerated. The base case assumes that 98% of condemned animals are rendered and that the rest are incinerated. The likelihood that an animal condemned at AM inspection is rendered or incinerated is assumed to be independent of its BSE status. The means of disposal is important because animals that are incinerated cannot contaminate human food or animal feed.

Animals that do manifest the clinical signs of BSE can be identified by AM inspectors. It is also possible that farmers might hold back from slaughter animals with BSE signs to prevent the case from being discovered. It is difficult to estimate how effectively U.S. inspectors would be at detecting an animal with BSE signs because the disease has not been detected in this country. The USDA has conducted training for inspectors to make them aware of these signs. The effectiveness of inspectors at detecting other CNS diseases could in concept be used to estimate how effective they would be at detecting animals with clinical signs of BSE. In practice, however, the prevalence rate for these other diseases are often unknown. Our base case assumes that clinical BSE cases would be detected at AM inspection 90% of the time. Because this value is highly uncertain, our uncertainty analysis evaluates the impact of using a wide range of values on the results of our simulation (see Section 3.2.2).

3.1.2.3 Stunning

Stunning humanely renders animals unconscious for slaughter. It is usually performed by mechanical devices, most commonly captive bolts that may or may not penetrate the skull. One type of penetrating captive bolt is referred to as an "air-injected pneumatic stunner" because it injects a jet of air into the brain at the end of the cylinder stroke. Stunners that use air injection can deposit CNS tissue emboli in blood, heart, lung, and liver. Malfunctions in these devices both increase the probability that emboli will be created and the amount of emboli that will be deposited. However, based on our conversations with USDA personnel (in headquarters and in the field), individuals in the beef packing industry, and others, the base case assumes that air-injected stunning is not currently used in the U.S. cattle industry. Other scenarios evaluating past practices do assume the use of air-injected pneumatic stunning (see Section 3.2.2).

There is also some concern that other stunning methods may produce CNS micro-emboli that could contaminate blood (SSC, 2000b). The base case assumes that stunners not using air injection can create very small emboli that are found only in blood. The amount of emboli in the blood is not affected by whether the stunner malfunctions.

The discussion in Appendix 1 for the <emboli> parameter in the stunner parameter group provides additional background on the development of these assumptions.

3.1.2.4 Exsanguination

Following stunning, animals are bled. Bovine blood can be processed for human consumption, processed to make blood meal that can be used in ruminant feed, rendered, or disposed of. The base case assumes that 15% of blood is made into blood meal that has the potential to be used in cattle feed. The base case also assumes that blood collected for human consumption is not contaminated with emboli.

Blood collected to produce meal for animal consumption may become contaminated with CNS tissue if some of that tissue drips from the hole created by the stunner. The base case assumes that air-injected pneumatic stunners generate this type of contamination with 30% probability, and that when this contamination does occur, 4% of the infectivity in the brain ends up in the blood being collected. The base case assumes that stunners that do not use air injection never cause this type of contamination.

3.1.2.5 Disposition of Brain

Following exsanguination, the head is removed from the carcass. USDA has mandated inspection of some parts of the head that are collected for human consumption (*e.g*, tongue). Because brain is the tissue with the greatest amount of infectivity in an animal with advanced BSE, the disposition of the head is important. There are no available data on the fraction of brains collected for sale as human food. The base case assumes that 1% of the brains are removed for potential human consumption in the U.S. and that the rest are rendered.

3.1.2.6 Splitting and Aerosolization

After removal of the head, the carcass is split longitudinally with a saw to facilitate handling and further processing. When the carcass is split some spinal cord is aerosolized and can contaminate edible meat. Based on data from experiments that measured the amount of spinal cord associated protein deposited on the carcass during splitting (Harbour, 2001), the base case assumes that approximately 0.001% (2.5 mg) of the spinal cord contaminates edible meat. The base case further assumes that additional carcass treatments, like washing and steaming, do not reduce the amount of contamination. Documentation accompanying table <fracAerosol> in file splitter (see Appendix 1) documents this assumption.

3.1.2.7 Disposition of the Spinal Cord and Dorsal Root Ganglia

The vertebrae of the animal are arranged in a column that houses and protects the spinal canal. Because spinal cord and the dorsal root ganglia (DRG), which are nerve ends emerging from the spinal cord, can contain BSE infectivity, their disposition influences the extent to which meat recovered for human consumption may become contaminated. The magnitude of this contamination and which selections of meat become contaminated depend on whether a mis-split occurs, whether the slaughter plant uses advanced meat recovery (AMR), and whether it removes the spinal cord from the carcass. The extent to which AMR product becomes contaminated is particularly sensitive to mis-splits because they can leave behind pieces of spinal cord encapsulated in the vertebral column that are processed by AMR. This section first discusses the frequency of mis-splits, the proportion of carcasses processed using AMR, and the proportion from which the spinal cord is removed. Finally, it discusses how mis-splitting, AMR, and spinal cord removal influences contamination.

Mis-split frequency

Mis-splitting refers to the incomplete cutting of the spinal column with a saw. A mis-split occurs when the cut veers off the vertical and terminates at a point short of the cervical vertebrae (carcasses are split caudal to cranial). The likelihood that mis-splitting will occur depends on the size and age of the animal (*e.g.*, calves are more likely to be mis-split than bulls or cows) and the proficiency of the saw operator. The rate and extent of mis-splitting influences the potential for spinal cord from an infected animal to contaminate human food, primarily in the Advanced Meat Recovery process (Section 3.1.2.8). The base case assumes that among animals below the age of 24 months, mis-splits occur 5% of the time, whereas for older animals, mis-splits occur 8% of the time. Table <probMS_AMR_SCRemove> in file splitter (see Appendix 1) details estimates of the rate and extent of mis-splits.

The proportion of cattle processed using AMR

Once the carcass is split, the disposition of the spinal cord depends on whether or not the slaughter facility processes the vertebrae using advanced meat recovery (AMR). AMR machines process bones to recover meat remaining after the hand deboning process is completed. USDA rules allow the AMR product to be labeled as "meat". Approximately 70% of fed cattle and 60%

of cows are processed in facilities that use AMR (Sparks Companies, 1999). The base case assumes that AMR is used to process no animals below the age of 12 months, 65% of animals between the ages of 12 and 23 months, and 60% of animals 24 months of age or older.

Spinal cord removal – Plants that use AMR

An FSIS directive requires that the spinal cord be removed from the vertebral column before the backbones enter the AMR process. The base case assumes that spinal cords are removed with 98% probability in plants using AMR. Spinal cords removed in this manner are rendered. In the event that spinal cord is not removed prior to AMR, it can contaminate the AMR product, although the probability of this occurring is small. In addition, if the carcass is mis-split, the spinal cord that remains encapsulated in the spinal canal (usually a small portion of the spinal cord) contaminates AMR product unless it is removed by facility personnel. Whether an AMR processing system is used depends on the size and age of the animal (*e.g.*, calves are not likely to go through AMR). The amount of spinal cord left behind that can contaminate edible meat also depends on the age and type of the animal (*e.g.*, for steers and heifers, the lumbar area does not go through AMR because T-bone steaks are more profitable).

Spinal cord Removal – Plants that do not use AMR

If a facility does not use AMR, FSIS does not require removal of the spinal cord from the carcass. However, some slaughterhouses choose to remove it and send it to rendering. The base case assumes that spinal cords are removed with 50% probability in plants that do not use AMR. If the spinal cord is not removed, it remains in certain cuts of beef and is hence available for potential human consumption (*e.g.*, T-bone steak). In addition, spinal cord left in the carcass can contaminate the boning table. Finally, a small fraction of the spinal cords removed from steers and heifers are destined for human consumption.

Fraction of spinal cord and DRG that contaminate meat recovered for human consumption

The DRG are firmly attached to the bones of the spinal column and are not removed even if the spinal cord is removed. The disposition of the DRG depends on the cuts of beef recovered for human consumption (which depend on the age of the animal) and on the use of AMR processing systems. For example, some cuts of meat from young animals, such as steers and

heifers, might be sold with the vertebrae attached (*e.g.*, T-bone steaks), and in those particular circumstances DRG can reach the consumer. However, it is important to note that even if DRG reaches the consumer, it is unlikely to be consumed unless the bone is aggressively cleaned. In other regions of the vertebral column, DRG will remain attached to the bone because they are unlikely to be removed by standard deboning operations. The vertebrae and DRG from young animals are likely to be rendered. For older animals (*e.g.*, bulls and cows) that are deboned by hand, DRG will not reach the consumer and will instead be rendered.

If the spinal column is processed using AMR, the DRG are likely to contaminate the AMR product. For young animals, only a fraction of the vertebral column and DRG will be processed using AMR because parts of the backbone are contained in high value bone-in cuts of meat. For older animals, such as bulls or cows, all vertebrae are likely to be processed using AMR. If the facility does not process the spinal column using AMR, other technology, such as vibration or hand held knives (*e.g.*, Whizzard knives), are used to recover the remaining meat attached to the bones. Because of the location of the DRG and the presentation of the backbones on the boning table, these knives are unlikely to incorporate DRG or spinal cord into meat or ground beef.

Tables <fracDRGInMuscle>, <fracDRGInAMRMeat>, and <fracDRGInBone> in file splitter (see Appendix 1) detail the fraction of the infectivity in DRG that ends up contaminating muscle, AMR product, or remains connected to the bone, respectively. These values depend on whether a mis-split occurs, the use of AMR, and on whether the spinal cord is removed. Tables <fracSCInMuscle>, <fracSCInAMRMeat>, and <fracSCInBone> in file splitter (see Appendix 1) provide the corresponding assumptions for spinal cord contamination.

3.1.2.8 Postmortem Inspection

Organs and tissues from cattle passing AM inspection are inspected *postmortem* (PM) to ensure fitness for human consumption. FSIS regulations require that the whole animal be condemned when certain diseases are suspected, while for other diseases and conditions, only some tissues are excluded from use in human food. There are no visible characteristics of BSE cattle that can be detected at PM inspection. Nevertheless, the base case assumes that some infected animals or tissues from animals with BSE are condemned at PM inspection for reasons other than the presence of BSE. These condemnation rates have been measured and reported by

FSIS (Table 3-2). The FSIS data specify rates by age and gender. The base case rates appear in Table <probPassPM> in file PMInspector (see Appendix 1).

3.1.2.9 Processing

After the carcass is split, meat for human consumption is recovered. Some potentially infectious tissues may be purposely recovered for potential human consumption. The existence and quantity of infectivity in specific tissues depends on the age of the animal and the elapsed time since infection (see Section 3.1.2.1). BSE infectivity potentially available for human consumption can come from specific tissues including cattle brain, spinal cord, cuts of meat with spinal cord or DRG, intestine, and from edible meat contaminated with infectious tissues (Section 3.1.4). Not all BSE infectivity available for potential human exposure is actually consumed. Rates of waste during distribution and in the home, portion sizes, and other factors will influence actual human exposure.

3.1.3 Rendering and Feed Production

Rendering is a process that recovers useful materials like fat, tallow, and protein, by cooking the animal remains, separating the products, and by further processing and purifying the resulting meat and bone meal (MBM). MBM is a rendering product rich in protein that can be used as a feed supplement, among other uses. If the remains of an infected animal, including either a sheep with scrapie or a bovine with BSE, are made into MBM that is then fed to cattle, additional animals could become infected. Current regulations in the U.S. (Food and Drug Administration, 1997) prohibit the feeding of mammalian derived protein to other ruminants with some exemptions. The feed ban does not restrict the use in ruminant feed of porcine protein, equine protein, ruminant blood, ruminant milk, plate waste, or gelatin. Other sources of protein, primarily of vegetable origin (*e.g.*, soy), are also widely used to supplement livestock rations. The extent of compliance with the feed ban in rendering and feed formulation influences the extent of possible cattle exposure to infectivity from a rendered diseased animal. Infectivity can also be eliminated as a result of using ruminant derived materials in ways that do not lead to any potential exposure among U.S. cattle (*e.g.*, export). Figure 3-7 illustrates our characterization of how materials flow through rendering plants, feed formulation plants, and to the farm.