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## Quantitative risk assessment of the risks associated with the importation of pigs to abattoirs

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*Summary:* This paper presents a quantitative risk assessment method based on the portrayal of risks using scenario trees, the translation of evidence into probability curves and the aggregation of scenarios using Latin Hypercube simulation. An example of a quantitative risk assessment on the importation of swine for slaughter illustrates the interpretation of evidence of two swine disease risks: pseudorabies (Aujeszky's disease) and brucellosis.

**KEYWORDS:** Abattoirs – Animal importation – Pigs – Quantitative risk assessment.

### INTRODUCTION

Government officials who regulate the importation of animals and animal products are asked to make decisions almost daily. When an importation request is received for which there exists no history of safe importation, a risk assessment is required.

For any risk assessment, information must be gathered on a number of variables or parameters. Usually, one of the first pieces of information to collect is a complete description of the commodity and the projected quantity to be imported. Next, the disease risks which exist in the exporting country must be identified. For each risk, information on the disease prevalence, disease epidemiology, agent properties and exposure scenarios are required. Data for these parameters are often quite limited and much uncertainty is associated with each parameter. This uncertainty may arise not only from incomplete information, but also from disagreement between information sources, inconclusive or imprecise data and variability in the measurements used (34).

The only way to incorporate all the facts which must be considered and to address the uncertainty is to conduct a quantitative risk assessment. The objective of this paper is to illustrate a quantitative risk assessment method which emphasizes the use of scenario trees to portray the risks concerned. A quantitative risk assessment on the importation of pigs destined for slaughter in Canadian abattoirs serves as an example. The presentation and format of the quantitative risk assessment, including the scenario trees, the parameters and the relevant data, illustrate the usefulness of this method.

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**QUANTITATIVE RISK ASSESSMENT METHOD**

Kaplan (27) presented a quantitative definition of risk in which risk (R) represents a complete set ( $\{ \}_c$ ) of triplets, as follows:

$$R = \{ \langle s_i, l_i, x_i \rangle \}_c$$

This definition answers the following three questions:

- a) What can go wrong? ( $s_i$ )
- b) How likely is that to happen? ( $l_i$ )
- c) If it does happen, what are the consequences? ( $x_i$ )

To visualize this set of triplets, Kaplan (27) included a simple table (Table I).

**TABLE I**  
*Representation of the quantitative definition of risk (27)*

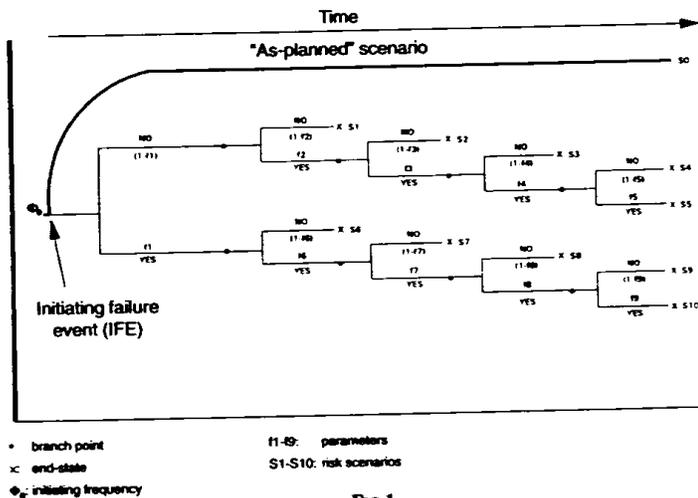
Scenario	Likelihood	Damage
$s_1$	$l_1$	$x_1$
$s_2$	$l_2$	$x_2$
$s_3$	$l_3$	$x_3$
.	.	.
.	.	.
$s_n$	$l_n$	$x_n$

The scenarios ( $s_i$ ) answer the first question: they describe what can go wrong. The second column gives the likelihood ( $l_i$ ) of each scenario, while the third column gives a measure, or measures, of the damage ( $x_i$ ) accompanying each scenario. If the table includes all possible scenarios, the set of triplets is complete. The damage index ( $x_i$ ) may be a multi-dimensional quantity, such as a vector in which the vector components represent animal deaths, human infection, wildlife infection, environmental contamination, etc. The damage may be time-dependent and/or uncertain (30).

Thus, one of the initial steps of a quantitative risk assessment is to identify the set of possible scenarios ( $s_i$ ). Mapping these in scenario trees as described by Kaplan (28, 30) is probably the best approach for appreciating and simplifying the complexity of the possible scenarios. Figure 1 presents the components of this map, beginning with the "as-planned" or "success" scenario, in which the undesired effects do not occur.

The initiating failure event (IFE) represents failure at some point in time and at some part of the as-planned scenario.

The branch points represent the various events which can occur following the IFE on a scenario path. Each branch point represents a frequency of occurrence or a fraction,



**FIG.1**  
**The "as-planned" scenario and the scenario tree emanating from an initiating failure event**

and each is expressed in units (e.g. effective contacts per infected animal, proportion infected animals which develop clinical signs).

Algebraic parameters are assigned to the IFE and to each branch point. For example  $\Phi_0$  may represent the initiating frequency of the IFE and  $f_1$  the split fraction of the  $f_1$  branch point. The damage index ( $x_i$ ) is the end-state of each scenario.

Each parameter ( $\Phi_0, f_1, f_2, \dots$ ) of the scenario tree has a probability curve. Triangular and uniform distributions represent two very useful probability curves which may be appropriate models to fit the data of many of the parameters.

The triangular distribution provides a convenient means of representing uncertainty when actual data are absent. The only three values needed for a triangular distribution are the minimum, the most-likely and the maximum. The minimum is the absolute number below which no value can exist for a given parameter. In a triangular distribution, the minimum means zero probability (as this value will never occur). The most-likely is the value which should occur most frequently, i.e. the mode of the distribution. The maximum value is an absolute ceiling and the probability of the maximum value itself is zero (33, 34). The three points of a triangular distribution are designated as follows:

- a = minimum
- b = most-likely
- c = maximum.

The mean of the distribution is  $(a + b + c)/3$ .

Where a range of possible values is identified for a parameter, while the value most likely to occur cannot be determined, the uniform distribution can be used. This represents one of the simplest means of representing the uncertainty surrounding a parameter. Each value across the range of the uniform distribution has an equal likelihood of occurrence. The two values for a uniform distribution are as follows:

- a = minimum
- b = maximum.

The mean of the distribution is  $(a + b)/2$ .

Parameters of the beta distribution can be used to calculate a mean and standard deviation of some parameter for which an observed occurrence of  $x$  events during  $n$  trials ( $x/n$ ) is available (34). The beta distribution with the following parameters:

$c = x + 1$  and  $d = n + 1 - x$

has a mean  $(\mu) = c/(c + d)$

and a standard deviation  $(\sigma) = \sqrt{\frac{(cd)}{(c+d)^2(c+d+1)}}$

With these moments, a triangular distribution can approximate the beta distribution. The three parameters for the triangular distribution are as follows:

- when  $x > 0$ ,  $a = \max(0, \mu - 3\sigma)$ ,  $b = x/n$  and  $c = \mu + 3\sigma$
- when  $x = 0$ ,  $a = \max(0, \mu - 3\sigma)$ ,  $b = \mu$  and  $c = \mu + 3\sigma$

where  $\max( )$  implies the maximum of either value.

For all simulations in the example below, 5,000 iterations of Latin Hypercube sampling were employed. This differs from Monte Carlo sampling in that the sample space for an input parameter is divided into strata, and input values are obtained by sampling separately from within each stratum instead of sampling from the distribution as a whole. The same number of stratifications exist with 5,000 iterations, and a sample is taken from each stratification without replacement (34).

Kaplan (29) described the "expert information" approach for the elicitation of evidence from experts. The experts are asked to contribute their experience and evidence relevant to a parameter ( $\lambda$ ).  $E_i$  represents the evidence provided by the  $i$ -th expert, while  $E_T$  is the total body of evidence upon which all the experts agree.  $E_T$  consists of evidence items  $E_1, E_2, \dots, E_m$ . With this set of evidence, the quantitative risk assessment analyst prepares a probability curve. If the experts agree that the probability curve represents a good interpretation of the evidence, a final consensual probability curve  $p_c(\lambda|E_T)$  is adopted. Figure 2 portrays the expert information approach of evidence elicitation. Depending on the parameter in question, the experts may represent many disciplines. In the quantitative risk assessment example presented in this paper, veterinary research scientists (particularly virologists and microbiologists) predominated in the group of experts.

In the assessment of the risks associated with the importation of animals and animal products, many sources of information are used. First and foremost are the sources for foreign animal disease awareness. In most countries, gathering information on and increasing awareness of the global distribution of exotic diseases are ongoing activities. Membership of the Office International des Epizooties (OIE), and the use of OIE publications and the *FAO/OIE/WHO Animal Health Yearbook*, are essential.

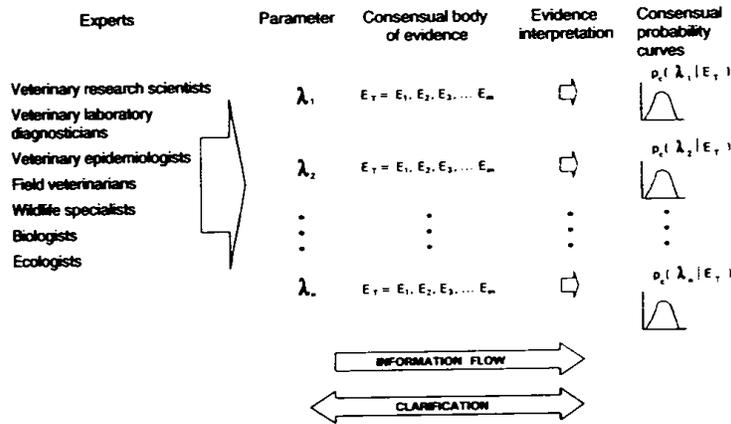


FIG. 2

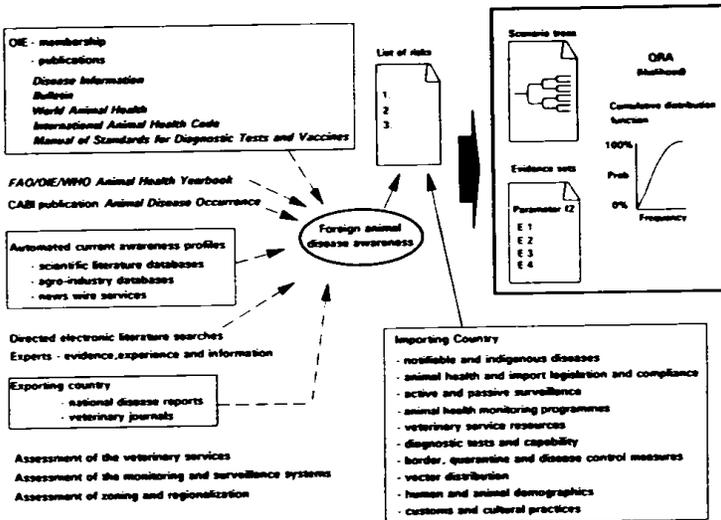
The elicitation of expert information and the interpretation of this evidence into probability curves

Other sources support this process, including the Centre for Agriculture and Biosciences International (CABI) publication *Animal Disease Occurrence*, automated current awareness profiles, directed literature searches and animal health reports from the exporting country. To identify the list of disease risks, foreign animal disease awareness must be complemented by knowledge of the indigenous and notifiable diseases and animal health legislation in the importing country.

Figure 3 illustrates the flow of information to provide foreign animal disease awareness and some of the other sources which provide evidence for the quantitative risk assessment. It is important to note that inputs include the assessment of the Veterinary Services, monitoring and surveillance systems and (if applicable) the assessment of zoning and regionalization data. Information on the epidemiology of the disease, the agent, the commodity, the exposure of the agent in the importing country and the risk reduction measures, all contribute to the scenario trees and evidence sets. The information flow facilitates the interpretation of this evidence into probability curves and, from these, the probability of the frequency of a particular end-state can be computed.

The following is a summary of the steps for the quantitative risk assessment method presented in this paper, adapted from Kaplan (30):

- a) Identify the as-planned scenario which represents importation without any damage.
- b) Identify the IFEs which are points of departure from the as-planned scenario.
- c) Establish the scenario tree for each IFE, to give a complete set of scenarios.
- d) Identify the damage indices ( $x_i$ ) which are the end-states of the scenarios.
- e) Assign algebraic parameters to the scenario trees and units for each parameter.



OIE: Office International des Epizooties  
 FAO: Food and Agriculture Organisation of the United Nations  
 WHO: World Health Organisation  
 CABI: Centre for Agriculture and Biosciences International  
 QRA: quantitative risk assessment

FIG. 3

#### The sources and flow of information for the quantitative risk assessment of the importation of animals and animal products

f) List a set of evidence for each parameter ( $E_T$ ).

g) Calculate  $P(\Phi)$  for each scenario path, e.g.  $P(\Phi_1) = P(\Phi_0) \times P(f_1) \times P(1-f_2)$  and calculate  $P(\Phi_T)$  for each end-state, e.g.  $P(\Phi_T) = P(\Phi_1) + P(\Phi_3) + P(\Phi_5)$  using Latin Hypercube simulation.

h) Portray the cumulative distribution function for each end-state and state the 99% probability of less than some frequency of occurrence of the damage event (expressed in the appropriate units for the given end-state).

### QUANTITATIVE RISK ASSESSMENT ON THE IMPORTATION OF PIGS TO ABATTOIRS

Importation into Canada of swine from the United States of America (USA) for immediate slaughter has never occurred. During the 1960s, the presence of hog cholera (classical swine fever) and, in the 1970s, the presence of pseudorabies (Aujeszky's

disease), represented the main deterrent to such importation. At present, breeding swine are imported, although these animals are subjected to a thirty-day quarantine with serological tests for pseudorabies and *Brucella suis* infection. The States from which the importation is proposed are referred to here as simply States A and B, in order not to detract from the purpose of using this example. For each of the two disease risks, pseudorabies and *B. suis* infection, the as-planned scenario and the IFE are described, the scenario tree and parameters are listed and graphically presented, and the evidence sets and simulations are provided.

## PSEUDORABIES DISEASE RISK

### As-planned scenario

The as-planned or success scenario ( $S_0$ ) represents the desired scenario path. This is a statement of the events of the importation without the entry of pseudorabies virus (PRV) into Canada.

The events of the success scenario are as follows:

a) Importation of slaughter swine (pigs) from States A and B:

- Accompanied by a United States Department of Agriculture (USDA) certification of origin from swine herds not known to be pseudorabies-infected and from States which possess Stage III status of the USDA Swine Brucellosis Control/Eradication Program.

- Transported in trucks, which are cleaned prior to loading and sealed by the USDA; the truck seals are examined by inspectors from Agriculture Canada at the border and again at the abattoir.

- Transported through States designated as Stage III, Stage IV and Stage V of the Pseudorabies Eradication Program, except in the case of swine originating from State A, for which transportation on a specified interstate highway is permitted through a State having a Stage II status.

- Slaughtered within eight hours of entering Canada and within four hours of arrival at the abattoir.

- Trucks and abattoir pens cleaned, with disposal of manure by rendering, following unloading and slaughter of the swine.

- Trucks to return directly to the USA without any possibility of contact with domestic livestock.

b) No introduction of PRV into Canada.

### Initiating failure event

The IFE represents the entry of PRV into Canada through the importation of slaughter swine from the USA.

### Scenario tree and parameters

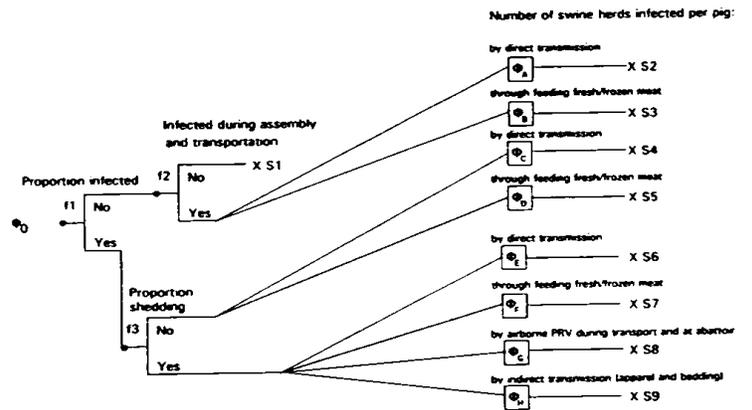
The following parameters are used:

- $\Phi_0$  - projected number of slaughter pigs imported from States A and B per year, if the importation is permitted

- $f_1$  – proportion of pigs infected with PRV
- $f_2$  – proportion of non-infected pigs which become infected during assembly and transportation
- $x$  – end-state for any scenario path
- S1 – scenario path of non-infected pigs which remain non-infected during the period of assembly and transportation
- $\Phi_A$  – number of Canadian swine herds infected via direct transmission per pig which was infected during the period of assembly and transportation
- $\Phi_B$  – number of Canadian swine herds infected via vehicle-borne transmission per pig (carcass) which was infected during the period of assembly and transportation
- $f_3$  – proportion of PRV-infected swine which are shedding virus in excretions, secretions or respiratory droplets
- $\Phi_C$  – number of Canadian swine herds infected via direct transmission per pig which was infected, but not shedding, at the time of removal from the herd of origin
- $\Phi_D$  – number of Canadian swine herds infected via vehicle-borne transmission per pig (carcass) which was infected, but not shedding, at the time of removal from the herd of origin
- $\Phi_E$  – number of Canadian swine herds infected via direct transmission per pig which was infected and shedding at the time of removal from the herd of origin
- $\Phi_F$  – number of Canadian swine herds infected via vehicle-borne transmission per pig (carcass) which was infected and shedding at the time of removal from the herd of origin
- $\Phi_G$  – number of Canadian swine herds infected via airborne transmission per pig which was infected and shedding at the time of removal from the herd of origin
- $\Phi_H$  – number of Canadian swine herds infected via indirect transmission per pig which was infected and shedding at the time of removal from the herd of origin
- S2 – scenario path of non-infected pigs which become infected during assembly and transportation and result in  $x$  herd infections per year via direct transmission
- S3 – scenario path of non-infected pigs which become infected during assembly and transportation and result in  $x$  herd infections per year via vehicle-borne transmission
- S4 – scenario path of infected, but non-shedding, pigs which result in  $x$  herd infections per year via direct transmission
- S5 – scenario path of infected, but non-shedding, pigs which result in  $x$  herd infections per year via vehicle-borne transmission
- S6 – scenario path of infected and shedding pigs which result in  $x$  herd infections per year via direct transmission
- S7 – scenario path of infected and shedding pigs which result in  $x$  herd infections per year via vehicle-borne transmission
- S8 – scenario path of infected and shedding pigs which result in  $x$  herd infections per year via air-borne transmission
- S9 – scenario path of infected and shedding pigs which result in  $x$  herd infections per year via indirect transmission

S2 + S3 + ... + S9 – aggregation of all scenario paths with the same damage index of  $x$  herd infections per year.

Figure 4 shows the scenario tree for this risk.



$\Phi_0$ : number of slaughter swine imported per year  
 PRV: pseudorabies virus

FIG. 4

**Scenario tree emanating from the pseudorabies virus initiating failure event**

**Evidence set for each parameter**

*Evidence*

**E<sub>1</sub>** Transport of pigs from States A and B would probably involve the use of 48½-ft long, wide-body trucks carrying up to 283 pigs each. The recommended floor areas for transport of a 230 lb pig are 4.4 sq. ft in hot weather (>75°F), 4.1 sq. ft at 60-75°F and 3.7 sq. ft at <60°F (J. Rawlins, unpublished findings). An average of 250 pigs per tractor-trailer truck is a reasonable estimate. A single lot of 250 pigs probably originates from between one and 25 herds, with between 10 and 250 pigs being contributed per herd.

**E<sub>2</sub>** Estimates of the number of slaughter pigs include a minimum of 25,000, a maximum of 500,000 and a "most-likely" figure of 100,000. The majority would probably be imported into the province of Ontario. The province of Quebec may import some pigs, but the importation of pigs into Ontario would probably permit the abattoirs in Quebec to purchase more Ontario pigs. Producer contracts with abattoirs would probably represent the usual arrangements (D. Adams, unpublished findings).

*Distribution for  $\Phi_0$*

This parameter was represented by a triangular distribution having the following values: a = 25,000, b = 100,000 and c = 500,000.

$f_1$ *Evidence*

**E<sub>1</sub>** Under the USDA Pseudorabies Eradication Program, both State A and State B possess Stage III status, and have the following swine population and known number of pseudorabies-infected herds:

– State A: 13,000 swine herds, 225,000 breeding swine, 1,875,000 pigs and 30 known infected herds (31 March 1993)

– State B: 8,600 swine herds, 175,000 breeding swine, 1,180,000 pigs and no known infected herds (31 March 1993) (6, 9, 43).

**E<sub>2</sub>** Fifteen “farrow-to-finish” herds were selected from 104 swine herds quarantined for PRV. Selection was based on the following criteria:

- ≥ 75% of sows seropositive for PRV
- no previous use of PRV vaccine in the “growing-finishing” section of the herd
- quarantined for at least six months
- located in a low prevalence area of the State of Minnesota.

The growing-finishing sections of four herds remained seronegative throughout the duration of the one-year study, four remained seropositive throughout, four became seronegative and three herds became temporarily seronegative and later reverted to seropositive status (35). Thawley *et al.* (42) had earlier noted that segregation of pigs at weaning enabled offspring to remain free of infection.

**E<sub>3</sub>** Serological evaluation of a representative sample of “finishing” pigs (29) in 27 swine herds quarantined for PRV was of limited value in identifying PRV-infected herds. Of the 27 herds, 19 contained PRV-seropositive female breeding pigs, while only 12 (63%) of these herds contained at least one seropositive finishing pig (3).

**E<sub>4</sub>** The seroprevalence of PRV antibodies in finishing pigs of six large swine herds in Illinois ranged between 0.7% and 97.3%. One herd, which had been recognized as infected more than 10 years ago, had 82% seroprevalence. Two recently-infected herds showed seroprevalences of 94.8% and 97.3%. Two recently-vaccinated finishing herds revealed 0.70% and 0.9% seroprevalences (25).

**E<sub>5</sub>** In 59 (42%) of 142 swine herds quarantined for PRV, less than 20% of the breeding age females were PRV-seropositive, while only 4 (7%) of these herds contained seropositive finishing pigs (29 pigs tested). Of the 83 (58%) herds with ≥20% seropositive females, 49 (59%) herds contained seropositive finishing pigs (36).

**E<sub>6</sub>** State A has approximately 60% of the total swine population of the two States (43). The importation would probably be based proportionally on the swine population of each State. However, since State A is closer to the abattoirs in the province of Ontario, this may mean that a larger number of pigs are imported from State A than from State B.

No known infected herds are to supply pigs for importation into Canada. To take into account the fact that unknown infected herds may exist and that errors do occur, this parameter ( $f_1$ ) was based on a range of herd prevalences of 1/13,000 to 30/13,000 in State A. The following assumptions were made:

– proportions for the importation of pigs from States A and B are 0.60 and 0.40, respectively

– infection is present in “finished” pigs in no more than 50% of infected herds.

*Distribution for  $f_1$*   $\frac{1}{13,000}(-6)(-.5) \quad \frac{30}{13,000}(-6)(-.5)$

Two uniform distributions were integrated for this parameter, one representing the prevalence of herd infections having values  $a = 2.3 \times 10^{-5}$  and  $b = 6.9 \times 10^{-4}$ , and the other representing the within-herd prevalence for the pig population, where the following values were used:  $a = 7 \times 10^{-3}$  and  $b = 9.7 \times 10^{-1}$ .

0.7%      97.3%      on  $E_4$   
 $f_2$

*Evidence*

**E<sub>1</sub>** In fattening swine, the incubation period is 3-5 days (38). The time required for assembly, transportation and stockage at the abattoir prior to slaughter is up to 18 hours.

**E<sub>2</sub>** A binomial expression elaborated by Beal (unpublished findings) gives the probability  $P(0)$  of no infected and shedding pigs in a group of 250 pigs per truck, using the following parameters:

$p_H$  = proportion of herds infected ( $2.3 \times 10^{-5} - 6.9 \times 10^{-4}$ )

$p_A$  = mean within-herd prevalence ( $7.0 \times 10^{-3} - 9.7 \times 10^{-1}$ )

$p_{SH}$  = proportion of infected animals which are shedding ( $1.0 \times 10^{-2} - 5 \times 10^{-2}$ ) (from parameter  $f_3$ )

$n$  = number of animals contributed per herd (10-250)

$k$  = number of herds contributing to tractor-trailer (1-25).

Therefore:

$$P(0) = [(1-p_H) + p_H \{ (1-p_A) + p_A [1-p_{SH}] \}]^n$$

A uniform distribution was used for each parameter in the above expression. The value of  $P(0) = 0.996$  was computed. Therefore, the probability of at least one infected and shedding pig per truckload of 250 pigs is  $\{1-P(0)\}$ .

Without a disease model to answer the question of how many pigs would become exposed and infected per shedding pig, a range of 1-10 new infections per truckload (in which there is at least one PRV-shedding pig) was used.

*Distribution for  $f_2$*

A uniform distribution was used, where  $a = 1$  and  $b = 10$ , in the expression  $P(\geq \text{one PRV shedding pig}) \times \text{uniform}(1,10) \times (1/250)$ .

 $f_3$ *Evidence*

**E<sub>1</sub>** Recrudescence of virus following corticosteroid treatment resulted in virus shedding after a lag period of between 4 and 11 days. The maximum amount of virus

was  $3.6 \log_{10}$ , i.e. 80 times less than the values reported by Donaldson *et al.* (21) in acutely infected pigs (37).

$E_2$  Finished pigs are unlikely to be shedding because of the predisposition to infection at pre- and post-weaning ages (M. Schoenbaum, unpublished findings). The proportion of infected slaughter pigs which are shedding during assembly, transportation and slaughter is considered to be in the range of 0.01-0.05.

#### Distribution for $f_3$

A uniform distribution was employed here, for which the minimum and maximum values are  $a = 0.01$  and  $b = 0.05$ .

$\Phi_A$

#### Evidence

$E_1$  Epidemiological investigation reports on 631 new herd infections in 41 States in 1989, revealed the most probable source of herd exposure to be infected domestic and feral swine (in 48.6% of cases), contacts with contaminated fomites or infected swine carcasses (1.1%) and area spread through unspecified mechanisms (49.6%) (13).

$E_2$  Escape and non-retrieval from federally-inspected abattoirs does not exist. No such occurrences were recorded between 1980 and 1992, when a total of more than 12 million pigs was slaughtered annually in approximately 40 federally-inspected abattoirs (F. Moulin, unpublished findings).

$E_3$  Between 1986 and 1991, the Ontario Pork Producers Marketing Board recorded two tractor-trailer overturns in which pigs escaped onto the roadway. In both cases, the pigs were retrieved (J. Rawlins, unpublished findings). The number of pigs slaughtered in federally-inspected abattoirs in the province of Ontario amounted to 22,412,515 pigs over the same period (4). Estimating that at least 25% of these pigs were transported by tractor-trailer trucks over various distances, zero pigs escaped (from a total of 5,603,129 pigs transported to slaughter by this means). To simplify the scenario, an infected pig which escapes is considered to result in exposure and infection of a single herd.

#### Distribution for $\Phi_A$

A triangular distribution was used to approximate the beta distribution which, for these data, has a mean ( $\mu$ ) of  $1.8 \times 10^{-7}$  and a standard deviation ( $\sigma$ ) of  $1.8 \times 10^{-7}$ . The three parameters for this triangular distribution were as follows:

$$a = \max(0, \mu - 3\sigma)$$

$$b = \mu$$

$$c = \mu + 3\sigma$$

in units of herds infected per pseudorabies-infected pig which escapes.

$\Phi_B$

#### Evidence

$E_1$  Carcass pork from swine which become infected during assembly and transportation is not considered as a risk because of the 3-5 day incubation period (38).

Viraemia would not be present following assembly, transportation and rest at the abattoir, a period of less than 18 hours.

#### Distribution for $\Phi_B$

The value for this parameter was considered to be negligible. The frequency of occurrence was arbitrarily set as a uniform distribution having values  $a = 1 \times 10^{-5}$  and  $b = 1 \times 10^{-4}$  in units of herd infections per pig which was infected during assembly and transportation.

$\Phi_C$

#### Evidence and distribution for $\Phi_C$

The same evidence and distribution was used here as for the parameter  $\Phi_A$ .

$\Phi_D$

#### Evidence

$E_1$  Ham from pork infected with PRV, which was prepared by curing for seven days at  $7-8^\circ\text{C}$  in brine containing nitrate and sugar, showed little reduction in virus titres. After boiling, when internal meat temperature reached  $65^\circ\text{C}$ , virus was isolated from bone marrow on three of five occasions. Hams had to be cooked at  $90-95^\circ\text{C}$  for at least 120 min to ensure that an internal temperature of  $70^\circ\text{C}$  was reached to inactivate the virus (31).

$E_2$  In sausages, an internal temperature of  $60^\circ\text{C}$  is required to inactivate PRV (31).

$E_3$  In muscle tissue, the survival time ranged between 11 and 36 days, depending on the temperature (11).

$E_4$  In pigs with clinically inapparent infection, PRV was not detected in carcass meat after storage for 72 h at  $1-2^\circ\text{C}$ ; in pigs which developed clinical manifestations, PRV was still recoverable from carcass muscle after storage for 30 days (31).

$E_5$  Following an infusion of  $10^8$  TCID<sub>50</sub> into the hind quarter of a freshly killed pig, no virus could be detected in muscle, bone marrow or lymph nodes after storage at  $-18^\circ\text{C}$  for 35 days (22).

$E_6$  The virus has been isolated from trigeminal ganglia and tonsils of naturally-infected animals until 13 months later (38).

$E_7$  Pork imports from the USA between 1975 and 1991 amounted to 542,818 metric tonnes (41), and in 1992 a further 11,370 tonnes of fresh/frozen pork and pork offal were imported (Table II). This gives an 18-year total of 554,188 tonnes. Table II shows that 43-61% of these imports between 1989 and 1992 consisted of fresh or frozen pork, such as bone-in pork, boneless pork, boneless backs, hams, bone-in backs, ribs, shoulders, butts, picnics, carcasses and sides. These percentages indicate that a figure of between 238,301 and 338,055 tonnes represents the range of fresh or frozen pork imported.

$E_8$  The average dressed weight of a slaughter pig in the USA in 1991 was 83 kg (43). For the most part, the fresh and frozen pork consisted of portions of carcasses, contributed by an unknown number of pig carcasses. However, in order to equate the pork with the number of imported pig carcasses, a value of 50 kg of pork per carcass is used. Therefore, between 4,766,020 and 6,761,100 pig carcasses contributed to the total

TABLE II

**Pork imports (metric tonnes) from the United States between 1988 and 1992**

(Figures do not include pork fat, lard, cured hams, bacon, ribs, picnics, skins and rinds, dry cured pork and sausage and pickled pork)

Product	1992	1991	1990	1989	1988
Pork bones	-	51.7	44.9	-	-
Pork casings	472.2	303.6	308.5	303.4	362.0
Pork scalps, lips, snouts	35.4	76.5	52.7	-	-
Pork skin, rinds	209.0	1,446.2	1,563.9	491.3	203.4
Pork brain, lung, spleen	-	54.8	6.4	-	-
Pork heart	3,051.3	4,063.7	2,781.9	3,205.6	3,667.8
Pork liver	19.1	89.5	449.7	305.5	407.4
Pork tongue	58.1	0.1	9.6	-	-
Pork tripe	57.3	0.3	3.0	-	-
Bone-in pork	2,206.2	2,809.9	2,300.6	2,127.6	101.1
Boneless pork	3,453.9	2,161.9	1,055.9	582.5	55.4
Boneless pork backs, etc.	303.4	492.2	454.0	490.8	967.6
Hams	291.8	79.5	76.4	832.6	539.0
Miscellaneous bone-in tails, feet	33.7	19.1	24.8	114.0	76.4
Bone-in pork backs, etc.	12.9	37.7	48.3	541.8	1,956.7
Pork bellies	319.5	634.9	70.1	37.7	13.3
Pork patties	97.1	79.7	4.8	-	-
Pork ribs	204.4	186.8	242.9	601.4	477.3
Pork shoulders, butts, picnics	42.0	36.5	-	2.2	19.1
Miscellaneous boneless pork head meat, jowls, etc.	28.6	233.3	-	-	-
Pork carcasses and sides	375.6	-	30.7	-	167.4
Pork kidneys	-	-	-	87.7	-
Mechanically separated pork	-	-	-	809.1	-
<b>Total</b>	<b>11,370.0</b>	<b>12,569.8</b>	<b>9,606.9</b>	<b>9,876.1</b>	<b>9,910.7</b>

Source: Agriculture Canada, Meat Hygiene Import Control System

importation. There is no doubt that this underestimates the actual number of pig carcasses which contributed carcass portions; however, the degree of underestimation is uncertain.

In ten northern and central States in the USA, each having over one million swine and likely to export pork to Canada because of proximity, the prevalence of pseudorabies herd infections on 31 March 1993 was 6,541/135,214, or 4.8% (6). From the evidence presented for parameter  $f_1$ , approximately 50% of these herds would be expected to have infections in the finishing pigs and, in these herds, a mean within-herd prevalence of 49% would be expected. Relating these figures to the number of imported

pig carcasses indicates that between 56,048 and 79,511 pseudorabies-infected pigs contributed pork over the 18 years of importation.

$E_9$  Pseudorabies infection has never occurred in Canada. Over the period 1975-1992, the importation of between 56,048 and 79,511 pseudorabies-infected pigs in the form of carcass meat has resulted in zero occurrences of pseudorabies. The extent to which the discarding of uncooked scraps of pork to swine occurs in Canada is not known; however, to date this activity has not resulted in pseudorabies. The evidence for parameter  $f_3$  indicates that 95-99% of infected pigs imported as carcass pork were non-shedding.

*Distribution for  $\Phi_D$* 

A uniform distribution was used to approximate the beta distribution which, for these data ( $E_9$ ), has mean ( $\mu$ ) values of  $1.3 \times 10^{-5}$  and  $1.9 \times 10^{-5}$ . These were used as the minimum and maximum values in the case of infected and non-shedding pigs. The minimum and maximum values of the uniform distribution for shedding pigs were  $2.5 \times 10^{-4}$  and  $1.8 \times 10^{-3}$ , respectively.

 $\Phi_E$ *Evidence and distribution for  $\Phi_E$* 

The same evidence and distribution were employed here as for the parameter  $\Phi_A$ .

 $\Phi_F$ *Evidence and distribution for  $\Phi_F$* 

The same evidence and distribution were used here as for the parameter  $\Phi_D$ .

 $\Phi_G$ *Evidence*

$E_1$  In a 24-hour period, four pigs shed a mean amount of  $\log_{10} 5.3$  TCID<sub>50</sub> (50% tissue culture infective dose) per pig via aerosol on day 2 following experimental intranasal infection with  $\log_{10} 6.8$  TCID<sub>50</sub> per pig of a specific strain of virus. The pigs were sampled on days 2, 3 and 4 following infection (21).

The results reported by Donaldson *et al.* (21) were obtained following intranasal infection of young pigs (35-45 kg) infected with massive doses of virus ( $5.7-8.1 \log_{10}$  TCID<sub>50</sub>). Such a challenge is much higher than the level of infection which can be expected from potentially infected pigs of market weight (G. Dulac, unpublished findings).

$E_2$  A retrospective study of a series of pseudorabies outbreaks in Yorkshire (United Kingdom) suggested that 7 of 11 outbreaks could have resulted from airborne virus. In one instance, airborne virus could have caused infection up to 9 km from one source. These outbreaks took place in November-December 1982 (24). At that time of the year in the United Kingdom, the temperature is cold and the relative humidity is high, i.e. above 60% (data from United Kingdom meteorological maps). In Yorkshire, the pig population is high and the number of young weaner pigs infected with pseudorabies was undoubtedly high. This would not be expected with market-weight pigs imported from

low prevalence States. Such pigs would probably be infected as weaners and would become latently infected (G. Dulac, unpublished findings).

**E<sub>3</sub>** In Denmark, two outbreaks occurred in December 1986, ten in 1987, and forty-three in the first five months of 1988, apparently as a result of airborne transmission from Germany. Denmark had no outbreaks for more than a year before this. The virus isolates belonged to the same genome type (Group 11) as that found in areas of Germany bordering Denmark (2). By the end of 1986, a surveillance programme which included the testing of all breeding boars and boars over 100 kg in body weight at slaughter or at export had detected as few as 32 known infected swine herds from a total of 47,814 herds (1, 2).

**E<sub>4</sub>** The outbreaks in Denmark in 1987 and 1988 resulted from airborne transmission over water, at a time of year when the environmental temperatures were cold and the relative humidity was high over the North Sea. Also, at this time, a large output of virus was being generated in northern Germany, which hosts one of the greatest concentrations of pigs in the world. The conditions in Denmark are very different from those expected in central Canada, where the following conditions would prevail:

- a) source of virus would be minimal at worst
- b) transmission would be overland and there would be diffusion of virus by convection air current (less probability of transmission)
- c) the relative humidity would generally be much lower than that which prevails in Denmark in the winter.

Cold and humid conditions provide greater survival potential for PRV; such are the conditions in north-western Europe in the winter months (G. Dulac, unpublished findings).

Winds are usually stronger and the atmospheric turbulence is greater during the day than at night; thus, the concentration of infectious virus carried downwind is higher at night (26).

**E<sub>5</sub>** For intranasal infection, piglets require  $10^1$ - $10^3$  TCID<sub>50</sub>, young pigs approximately  $10^4$  TCID<sub>50</sub> and adult pigs  $10^4$ - $10^5$  TCID<sub>50</sub> (44, 45).

**E<sub>6</sub>** For intranasal infection, cattle require at least  $10^5$  TCID<sub>50</sub> (44).

**E<sub>7</sub>** Drying of PRV on glass at both 1°C and 22°C at 40-50% relative humidity resulted in a loss of 4 log<sub>10</sub> of virus, i.e. a reduction of 99.99% relative to the original virus titre (18).

**E<sub>8</sub>** In Denmark, airborne infections have spread from herds with fattening pigs, as the clinical symptoms in acutely infected fattening pigs are often combined with respiratory distress and coughing, which must increase the amount of airborne virus (2).

**E<sub>9</sub>** In market-weight pigs, the infection is likely to have occurred several weeks previously. Acute infection is likely to be rare, and spreading of virus by the respiratory route (as occurred in Denmark) is unlikely to happen (G. Dulac, unpublished findings).

**E<sub>10</sub>** Nasal excretion of virus occurs for 8-17 days with maximum titres between  $10^{5.8}$  and  $10^{8.3}$  TCID<sub>50</sub>. From oropharyngeal swabs, PRV can be isolated for 18-25 days with titres up to  $10^6$  TCID<sub>50</sub>. Virus is also excreted in vaginal and foreskin secretions for up to 12 days and in milk for 2-3 days (32, 45).

**E<sub>11</sub>** On the basis of Table IV of the article by Donaldson *et al.* (21) - particularly the data for day 2 - in a four-hour period, an infected pig releases a mean virus amount of 35,503,537 ( $10^{4.550}$ ) TCID<sub>50</sub>, with a standard deviation of 57,137,562 ( $10^{4.757}$ ) TCID<sub>50</sub>. The actual amount released follows a normal distribution with the above mean and standard deviation.

Table III shows the probability that the total amount of virus released in the four-hour period at the abattoir by a truckload of 250 pigs would exceed  $10^7$  TCID<sub>50</sub>, given the presence of various total numbers of infected and shedding pigs in the truckload.

TABLE III

*Likelihood of the release of airborne virus above a certain critical mass necessary for herd exposure and infection*

No. of infected and shedding pigs in the truckload	Z-score*	Probability ( $y > 10^7$ )**
25	6.38	$< 10^{-9}$
30	5.21	$< 10^{-7}$
35	4.38	$6 \times 10^{-6}$
40	3.754	0.0001
50	2.879	0.002

\* Z-score of the normal distribution

\*\* probability that the total amount of virus ( $y$ ) released in a four-hour period at the abattoir by a truckload of 250 pigs would exceed  $10^7$  TCID<sub>50</sub>, given various numbers of infected and shedding pigs present in the truckload

This amount of virus ( $10^7$  TCID<sub>50</sub>) was used as the critical mass of airborne virus required to achieve the delivery of an infectious respiratory dose of  $10^4$  TCID<sub>50</sub> to a pig within a Canadian herd.

*Distribution for  $\Phi_G$*

From evidence **E<sub>2</sub>** of parameter  $f_2$ ,  $P(0) = 0.996$  (the probability that no pigs are infected and shedding per truckload of 250 pigs).

Using the Poisson distribution approximation to the binomial distribution, the following expression (12) was used to express the probability of one, two, three, etc., infected and shedding pigs in a truckload of 250 animals:

$$P(x) = (e^{-\alpha} \alpha^x) / (x!)$$

where  $\alpha$  = mean of infected and shedding animals per truckload of 250 pigs

$$= |\ln [P(0) = 0.996]| = 0.004.$$

Thus:

$$P(1) = 4.0 \times 10^{-3}$$

$$P(2) = 8.0 \times 10^{-6}$$

$$P(3) = 1.1 \times 10^{-8}$$

etc.

Obviously, the probability of this scenario is extremely low. For computational purposes, in order to retain the scenario in the simulation, the frequency of  $\Phi_G$  was arbitrarily set as a uniform distribution having the following values:  $a = 2 \times 10^{-4}$  and  $b = 1 \times 10^{-3}$  in units of herd infections per pig which was PRV-infected and shedding.

$\Phi_H$

Evidence

**E<sub>1</sub>** At the optimum pH levels of 6-8, PRV inactivation at 37°C was 0.6 log<sub>10</sub> over 24 h (18), whereas at 4°C there was no measurable inactivation after 24 h.

**E<sub>2</sub>** Virus survived for up to 46 days at -8°C and for up to 10-30 days at 25°C on hay, wood and food (11).

**E<sub>3</sub>** PRV survived storage in liquid manure for 26 weeks at 4°C, but was killed within 16 weeks at 20°C (14).

**E<sub>4</sub>** In slurry, PRV was inactivated in 15 weeks at 5°C and in two weeks at 20°C. At 35°C, the virus was inactivated in 5 h (16).

**E<sub>5</sub>** In the environment at 22°C, the half-life of PRV was 18.8 min at 25% relative humidity (RH), 36.1 min at 55% RH and 17.4 min at 85% RH (39).

**E<sub>6</sub>** The low probability of infected and shedding pigs being present in a "lot" of pigs essentially reduces the chance of shed virus coming into contact with swine herds. There is an enormous dilution of an infectious dose due to faeces, urine, bedding and the water used to clean the abattoir floors. The possibility of exposure of swine herds to contact with PRV-contaminated trucks was eliminated through the risk reduction measure in the import conditions.

Distribution for  $\Phi_H$

The same distribution and values employed for parameter  $\Phi_C$  were used here.

Simulations

All simulations were performed using Latin Hypercube simulation with a commercial software programme (@Risk, Palisade Corporation, Newfield, New York, USA). The same number of iterations (5,000) were conducted for each scenario and the aggregation of scenarios (same end-state), as follows:

- Scenario 2:  $P(\Phi_2) = P(\Phi_0) \times P(1-f_1) \times P(f_2) \times P(\Phi_A)$
- Scenario 3:  $P(\Phi_3) = P(\Phi_0) \times P(1-f_1) \times P(f_2) \times P(\Phi_B)$
- Scenario 4:  $P(\Phi_4) = P(\Phi_0) \times P(f_1) \times P(1-f_3) \times P(\Phi_C)$
- Scenario 5:  $P(\Phi_5) = P(\Phi_0) \times P(f_1) \times P(1-f_3) \times P(\Phi_D)$
- Scenario 6:  $P(\Phi_6) = P(\Phi_0) \times P(f_1) \times P(f_3) \times P(\Phi_E)$
- Scenario 7:  $P(\Phi_7) = P(\Phi_0) \times P(f_1) \times P(f_3) \times P(\Phi_F)$
- Scenario 8:  $P(\Phi_8) = P(\Phi_0) \times P(f_1) \times P(f_3) \times P(\Phi_G)$
- Scenario 9:  $P(\Phi_9) = P(\Phi_0) \times P(f_1) \times P(f_3) \times P(\Phi_H)$
- Scenarios 2-9:  $P(\Phi_T) = P(\Phi_2) + \dots + P(\Phi_9)$ .

Table IV presents the statistical output of the simulation of the aggregation of all the scenarios (same end-state) and Figure 5 presents the cumulative distribution function (CDF) of  $P(\Phi_T)$ . The units are swine herd infections per year. From the CDF in Figure 5, there is a 99% probability of less than  $2.0 \times 10^{-2}$  swine herd infections per year of such importation. In other words, there is a 99% probability of less than one swine herd infection in 50 years.

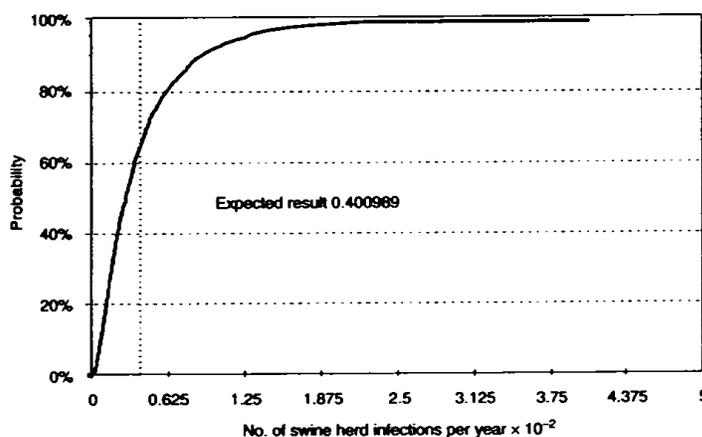


FIG. 5  
Cumulative distribution function curve for the end-state of pseudorabies swine herd infections

SWINE BRUCELLOSIS DISEASE RISK

As-planned scenario

The as-planned scenario is a statement of the events of the importation without the entry of *Brucella suis* (biovars 1 and 3) into Canada.

The as-planned scenario includes the same events as for pseudorabies risk, except that the outcome is no introduction of *B. suis* (biovars 1 and 3) into Canada.

Initiating failure event

The IFE represents the entry of *B. suis* into Canada through the importation of slaughter swine from the USA.

Scenario tree and parameters

The following parameters are used:

$\Phi_0$  - the projected number of slaughter pigs imported from States A and B per year, if the importation is permitted

TABLE IV

Latin Hypercube simulation statistics for the aggregation of scenarios 2 to 9 of the pseudorabies virus scenario tree and scenario 2, and the aggregation of scenarios 3 and 4, of the Brucella suis scenario tree

Statistics	Scenarios 2-9	Scenario 2	Scenarios 3 and 4
Expected/mean result	0.004010	0.014437	0.000858
Maximum result	0.040727	0.070598	0.007185
Minimum result	0.000056	0.000136	0.000010
Range of possible results	0.040671	0.070462	0.007175
Chance of positive result	100	100	100
Chance of negative result	0	0	0
Standard deviation	0.003968	0.010961	0.000832
Skewness	2.385173	1.411677	2.149338
Kurtosis	11.275600	5.172698	9.510391
Variance	0.000016	0.000120	0.000001
Errors calculated	0	0	0
Values filtered	0	0	0
Simulations executed	1	1	1
Iterations	5,000	5,000	5,000
Percentile probabilities (chance < = shown value)			
50%	0.00280	0.01140	0.00060
55%	0.00310	0.01270	0.00070
60%	0.00350	0.01410	0.00080
65%	0.00400	0.01570	0.00090
70%	0.00450	0.01740	0.00100
75%	0.00510	0.01930	0.00110
80%	0.00600	0.02180	0.00130
85%	0.00720	0.02510	0.00160
90%	0.00890	0.02990	0.00190
95%	0.01180	0.03690	0.00250
100%	0.04070	0.07060	0.00720

- $f_1$  - proportion of pigs infected with *B. suis*
- $x$  - end-state for any scenario path
- S1 - scenario path of non-infected pigs
- $\Phi_A$  - number of humans infected per pig which was infected at the time of removal from the herd of origin
- $\Phi_B$  - number of Canadian swine herds infected via indirect transmission per pig which was infected at the time of removal from the herd of origin
- $\Phi_C$  - number of Canadian swine herds infected via direct transmission per pig which was infected at the time of removal from the herd of origin
- S2 - scenario path of infected pigs resulting in  $x$  human infections per year via direct contact with an infected carcass
- S3 - scenario path of infected pigs resulting in  $x$  herd infections per year via indirect transmission
- S4 - scenario path of infected pigs resulting in  $x$  herd infections per year via direct transmission.

Figure 6 shows the scenario tree for this risk.

Evidence set for each parameter

Evidence and Distribution for  $\Phi_0$

The same evidence and distribution were used as are presented with this parameter for the pseudorabies risk.

Evidence

$E_1$  Swine Brucellosis Control/Eradication Program Stage III status was attained by State A in 1986 and by State B in 1975. The last case of swine brucellosis in State A was in 1970 (20).

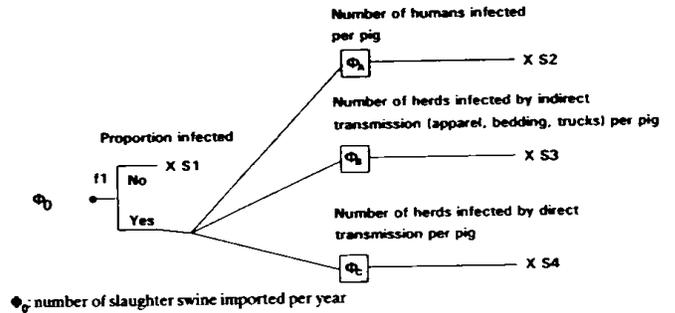


FIG. 6

Scenario tree emanating from the *Brucella suis* initiating failure event

**E<sub>2</sub>** The Brucellosis Stage III requirements include a two-year qualification period in which no more than one swine brucellosis-infected herd is identified, depopulated and tested, and determined to be free from the disease. To maintain Stage III status, a state must survey on a random basis at least five percent of its breeding swine annually. The status is lost if infection is disclosed with evidence of spread (8).

**E<sub>3</sub>** For State A, approximately 67,500 breeding swine were serologically tested and found negative (total population of 225,000 breeding swine  $\times$  0.05  $\times$  6 years) between 1987 and 1992. For State B, approximately 148,750 breeding swine (175,000  $\times$  0.05  $\times$  17 years) tested serologically negative for brucellosis between 1976 and 1992. Hence, approximately 216,250 serological tests for brucellosis revealed zero occurrences of infected breeding swine.

#### Distribution for $f_j$

A triangular distribution was used to approximate the beta distribution which, for these data, has a mean ( $\mu$ ) of  $4.6 \times 10^{-6}$  and a standard deviation ( $\sigma$ ) of  $4.6 \times 10^{-6}$ . The three values for this triangular distribution were as follows:

$$\begin{aligned} a &= \max(0, \mu - 3\sigma) \\ b &= \mu \\ c &= \mu + 3\sigma \end{aligned}$$

in units of proportion of pigs infected with *B. suis*.

$\Phi_A$

#### Evidence

**E<sub>1</sub>** The source of the majority of human brucellosis in the USA to date has been *B. suis*-infected swine (23).

**E<sub>2</sub>** Most cases of human brucellosis occur in workers in meat-packing plants and 90% of cases are related to slaughtering of pigs (40).

**E<sub>3</sub>** *B. suis* (biotypes 1 and 3) appears to have a much higher degree of pathogenicity for humans than other *Brucella* spp. found in the USA, and tissues of infected swine tend to have much higher numbers of *B. suis* organisms (19).

**E<sub>4</sub>** Between 1988 and 1992, a total of 467 cases of human brucellosis was reported in the USA (5, 7). **E<sub>2</sub>** indicates that approximately 420 (90%) of these cases can be attributed to exposure to *B. suis*-infected swine at slaughter.

**E<sub>5</sub>** A total of 18,544,000 sows, boars and stags were slaughtered at federally-inspected abattoirs in the USA between 1988 and 1991 (43). This represents an average of 4,636,000 per year, and therefore approximately 23,180,000 sows, boars and stags were federally inspected at slaughter over the five-year period 1988-1992.

**E<sub>7</sub>** From 1 January to 30 June 1993, 162,482 breeding swine were serologically tested for brucellosis at slaughter establishments in the USA. Of these, 320 (0.2%) were reactors (9, 10). Using this reactor rate as an estimate of the infection level in breeding swine

at slaughter indicates that approximately 45,652 (0.2%) of the 23,180,000 sows, boars and stags slaughtered between 1988 and 1992 were infected with *B. suis*. From **E<sub>5</sub>**, the 420 cases of human brucellosis resulted primarily from exposure to these 45,652 infected swine.

#### Distribution for $\Phi_A$

A triangular distribution was used to approximate the beta distribution which, for these data, has a mean of  $9.2 \times 10^{-3}$  and a standard deviation of  $4.5 \times 10^{-4}$ . The three values for this triangular distribution were as follows:

$$\begin{aligned} a &= \max(0, \mu - 3\sigma) \\ b &= x/n = 420/45,652 \\ c &= \mu + 3\sigma \end{aligned}$$

in units of humans infected per *B. suis*-infected pig.

$\Phi_B$

#### Evidence

**E<sub>1</sub>** Ingestion of feed contaminated by semen, urine and other discharges from infected boars and sows, and venereal transmission by boars possessing a localization of the infection in the genitalia, are the common methods of disease spread (15).

**E<sub>2</sub>** Under natural conditions, *Brucella* spp. behave as obligate parasites and do not pursue an existence independent of the animal hosts (17).

**E<sub>3</sub>** *B. suis* is the only recognized *Brucella* sp. which causes systemic or generalized infection leading to reproductive failure in swine. Infection is transmitted to susceptible swine through direct association with infected swine. The most important routes of infection are the alimentary and genital tracts. Brucellosis is a venereal disease in swine, which is transmitted to sows and gilts through the semen of infected boars. Suckling pigs are frequently infected by nursing dams. Clinical evidence of brucellosis in suckling and weaning pigs is usually absent. Swine can be experimentally infected by conjunctival or intranasal exposure with a suspension of *B. suis*. Organisms could probably also enter through scarified or, possibly, intact skin (19).

**E<sub>4</sub>** The possibility of herd infections occurring through indirect transmission is therefore very remote. One herd infection per 1,000-10,000 *B. suis*-infected pigs through indirect transmission in scenario 3 may be a reasonable estimate of the frequency.

#### Distribution for $\Phi_B$

A uniform distribution was used, with minimum and maximum values of  $a = 0.0001$  and  $b = 0.001$ .

$\Phi_C$

#### Evidence and distribution for $\Phi_C$

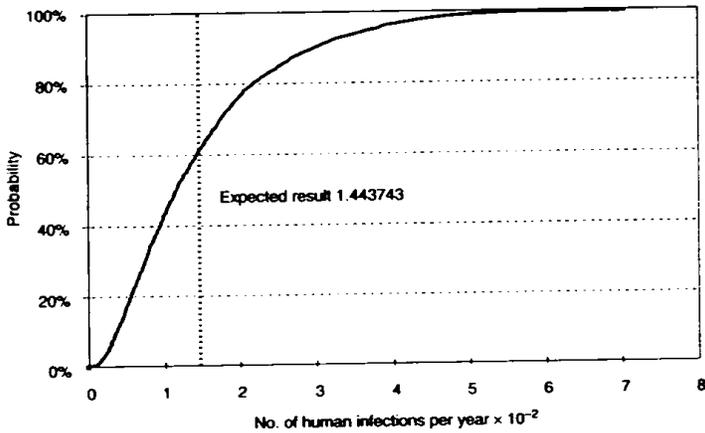
The evidence and distribution presented for the parameter  $\Phi_A$  of the pseudorabies risk were also employed here, but the units were swine herds infected per brucellosis-infected pig which escapes.

**Simulations**

Latin Hypercube simulations similar to those for the pseudorabies risk scenarios were performed, as follows:

- Scenario 2:  $P(\Phi_2) = P(\Phi_0) \times P(f_1) \times P(\Phi_A)$
- Scenario 3:  $P(\Phi_3) = P(\Phi_0) \times P(f_1) \times P(\Phi_B)$
- Scenario 4:  $P(\Phi_4) = P(\Phi_0) \times P(f_1) \times P(\Phi_C)$
- Scenarios 3 and 4:  $P(\Phi_T) = P(\Phi_3) + P(\Phi_4)$ .

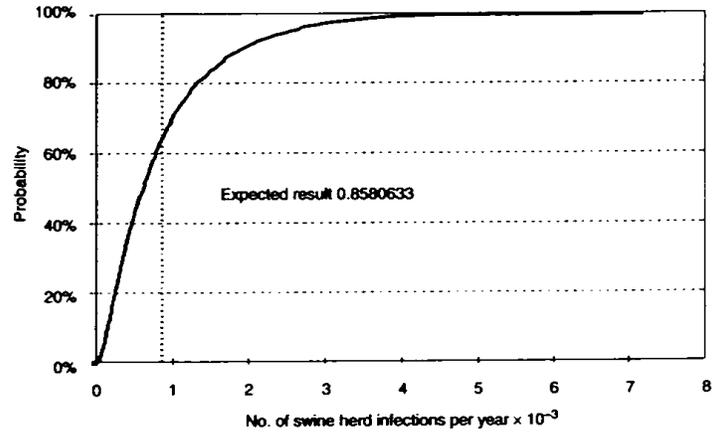
Table IV presents the statistical output of the simulations for scenario 2 and for the aggregation of scenarios 3 and 4. Figure 7 presents the CDF for scenario 2 in units of humans infected per year, and Figure 8 presents the CDF for  $P(\Phi_T)$  in units of swine herd infections per year.



**FIG. 7**

**Cumulative distribution function curve for the end-state of human brucellosis infections**

There is a 99% probability of less than  $5.1 \times 10^{-2}$  human infections occurring per year (99% probability of less than one human infection in 19 years) and a 99% probability of less than  $3.9 \times 10^{-3}$  swine herd infections per year (99% probability of less than one swine herd infection in 256 years).



**FIG. 8**

**Cumulative distribution function curve for the end-state of brucellosis swine herd infections**

**CONCLUSION**

The 99% probability of the frequency of some risk damage gives the decision-maker an indication of the likelihood of the risk. On the basis of this figure and an evaluation of the economic, social and political costs and benefits, the decision-maker is able to decide whether an importation is acceptable.

The quantitative risk assessment method described above offers an approach which clearly presents the risks, the scenarios, the parameters and the probability of the frequency of an event. The assessment of the risks associated with the importation of animals and animal products is made easier with this approach. The scenario trees provide a visual representation of the possible events. Data can readily be added, updated, corrected and re-interpreted when the risk assessment is presented in this format.

Another advantage of this approach is versatility. This quantitative risk assessment method can be adapted to virtually any commodity which is intentionally or unintentionally imported (e.g. animals, embryos, vials of semen, meat carcasses, portions of meat, milk or infectious materials). This is an extremely useful attribute, given the wide range of import commodities and infectious agents which exist.

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## ÉVALUATION QUANTITATIVE DES RISQUES LIÉS À L'IMPORTATION DE PORCS DESTINÉS À L'ABATTOIR. – R.S. Morley.

**Résumé :** Cet article présente une méthode d'évaluation quantitative des risques, basée sur l'utilisation de scénarios en schémas arborescents, la traduction des signes cliniques en courbes de probabilités et l'agrégation des scénarios à l'aide de la simulation Latin Hypercube. Un exemple d'évaluation quantitative des risques lors de l'importation de porcs destinés à l'abattoir montre comment on interprète les signes de risques pour deux maladies porcines : la maladie d'Aujeszky et la brucellose.

**MOTS-CLÉS :** Abattoirs – Evaluation quantitative des risques – Importation d'animaux – Porcins.

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## EVALUACIÓN CUANTITATIVA DE LOS RIESGOS ASOCIADOS A LA IMPORTACIÓN DE PORCINOS DESTINADOS AL MATADERO. – R.S. Morley.

**Resumen:** El autor presenta un método de evaluación cuantitativa de riesgos que se basa en la disposición de las distintas posibilidades en forma de esquemas arbóreos, la traducción de los signos de riesgos en curvas de probabilidades y el agregado de las posibilidades mediante la simulación Latin Hypercube. Un ejemplo de evaluación cuantitativa de riesgos asociados a la importación de porcinos destinados al matadero, muestra cómo se interpretan los signos de riesgos de dos enfermedades porcinas: la enfermedad de Aujeszky y la brucelosis.

**PALABRAS CLAVE:** Evaluación cuantitativa de riesgos – Importación de animales – Mataderos – Porcinos.

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