

## APPENDIX F

### LITERATURE REVIEW

The literature on epidemiology of highly infectious diseases can be divided into four large groups: spatial epidemiologic models and management systems, non-spatial epidemiologic models, economic analysis of control and eradication strategies, and papers covering a variety of related topics.

#### **Spatial epidemiological models**

Spatial epidemiological models generally use a GIS to forecast the diffusion of outbreaks of infectious diseases. Moutou and Durand (1994) analyze airborne diffusion of FMD with a predictive model that links epidemiological data associated to viral particle excretion and meteorological data related to the few days before the slaughter of animals. The model computes the expected quantity of viral particles that could be found in a 10 km radius around the outbreak in every space direction, and that originated on the breath of a sensitive animal. The model is used to define a risk area, according to the number and size of farms in the surroundings.

Casal et al. (1997) simulated atmospheric dispersion of virus using a model that has been developed for predicting the dispersion of toxic gases from chemical engineering plants. The results were compared with data from two outbreaks of Aujeszky's disease and two of FMD in which virus was believed to have been transported by air. The model provides estimates of the mean dose of virus received by an animal at a farm downwind.

The New Zealand Ministry of Agriculture and Fisheries developed a decision system for managing a FMD epidemic (Sanson et al., 1991). The system, known as EpiMAN, comprises a database management system, a geographic information system, a spatial simulation model of FMD and a number of expert systems. A number of studies were conducted to gather the data required by the system.

- Sanson and Morris (1994) used survival analysis linked to a GIS to estimate the probability of a farm contracting FMD due to local and windborne spread, where the independent factor is distance from a source infected farm. Historical data from the FMD epidemic of 1967-1968 in the UK were used to estimate diffusion probabilities, with the data set restricted to those farms in which the most likely reason for infection was recorded as local or windborne spread. Their findings show that the probability of FMD infection in the period covering one day prior to the appearance of clinical signs to 2 days after the signs appeared was 0.13 for farms within a 3 km radius from the source and 0.015 for farms within 3 and 5 km from the source.
- A survey of Southland farms in New Zealand was conducted to assess the potential for FMD dissemination through normal movement patterns of farm animals and materials over a period similar to

what would be expected from the time the virus arrived on a property to the time of diagnosis (Sanson et al., 1993). Each farmer participating in the survey was required to complete a diary, recording all movements of people, animals and materials onto or off the farm during a 14-day period. The mean number of movements recorded per farm was 50. The majority of movements occurred within the immediate neighborhood of the origin, with 31.5% and 56.5% of all movements occurring within 5 km and 10 km respectively. A radius of 100 km would contain 95% of all movements. The mean number of high risk movements that occurred over the 100 km radius was 3.4.

The EpiMAN system is now being adopted by the EU, and consists of a central database for farm information, a GIS for spatial data, epidemiological and economic simulation models, and expert systems containing factual knowledge about FMD (Nielen et al., 1996a). The aim of the system is to support decision makers in both the operational and tactical management during a FMD outbreak, but the system may also be used as a training tool. The system allows to list all farms in a determined area, and also predicts the size and movement of the virus plume. The main difference between the European and the New Zealand versions of EpiMAN is that the former includes an economic model to evaluate alternative control and eradication policies.

Studies in several European countries have been conducted to calibrate the system to the different conditions prevailing in different regions. Among these studies, a survey of Dutch farms was conducted to quantify contacts among farms (Nielen et al., 1996b). Farmers were asked to report all movements in and out of their farms during a two week period. These records were compared with regularly scheduled visits, such as AI technicians and veterinarians. A major result of the study was discovering the difficulty of farmers to accurately report all movements, even in a controlled experiment. This finding has major implications for FMD control. In case of an outbreak, producers are asked to remember all animal movements in and out of the farm in the previous 21 days and all other contacts in the previous 15 days. Exact identification of the days in which the movements occurred is also required to relate them to the date in which the outbreak was identified in the farm. This may prove to be very difficult, judging by the high number of contacts recorded by both the New Zealand and the European studies.

The European studies found that the average number of contacts per farm (91) was almost twice the number in New Zealand (50). This is likely due to differences in the livestock industries, and the smaller distances between farms in the Netherlands. Regression analysis showed that in both cases neither the pattern of movements nor the distance between farms or riskiness of the contacts are affected by farm characteristics. In other words, in case of an outbreak all farms should be treated as having equal risk of becoming infected. The relative size of the farm remains possibly the most important indicator at the start of an outbreak, when no other information is available; this is particularly relevant for airborne diffusion of the outbreak.

A similar but less developed information management system was used to analyze the spread of pseudorabies in Minnesota swine herds (Marsh et al., 1991).

Hungeford (1991) used a GIS to analyze three issues relevant to epidemiology: whether a disease is clustered, whether two diseases, or a disease and potential risk factors have the same distribution, and if there are specific definable relationships between the values of the same variable at different locations. Join count statistics (which relate actual and expected number of joins between areas with dissimilar values) and second order analysis (which compares the actual and expected distances between all points weighted by their values) give estimates of the magnitude and statistical significance of clustering in patterns.

Kitron et al. (1991) studied the association of tick distributions with soil type, potential vegetation cover and distance from waterways, and compared the dispersion patterns of tick-infested and uninfested deer in one northwestern Illinois county with the help of a GIS.

### **Non-spatial epidemiological models**

Non-spatial epidemiological models generally use a Markov chain or a state-transition model to analyze the spread of an outbreak of an infectious disease.<sup>14</sup> Markov chains are used to analyze the changes over time of systems that can be defined in terms of a number of possible outcomes or states that can occur. A Markov chain has two components: states and transition probabilities. States are defined as the possible groups (or situations) in which an individual can be at any particular moment. The transition probabilities represent the probability that an individual will move to state  $j$  in the next period when presently it is in state  $i$ . There are many types of Markov chains. First-order Markov chains are the ones most used in epidemiological studies. They have the following characteristics:

1. States and transitions are discrete (e.g., one per week).
2. The number of states is finite.
3. Transitions depend only on the current state, not on prior states. In other words, the whole history of the process is contained in the current state. To simplify the presentation, the transitions are usually presented in matrix notation; the matrix is known as the transition matrix.
4. Transition probabilities remain constant over time.

Markov chains are used to estimate the expected state of a system after a certain period of time (which may be infinite). By attaching payoffs to each state, it is possible to estimate the expected value of alternative policies (Taylor and Karlin, 1994). Markov models are more appropriate to model diseases which are more endemic (or static) than those based on the Reed-Frost equation which are better suited to model highly contagious diseases. Even though Markov models have been extensively used in both human and animal epidemiological studies, they will not be reviewed due to their limited use to model a FMD outbreak; references can be found in Carpenter (1988b).

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<sup>14</sup> A more comprehensive view of simulation models applied to epidemiology can be found in Hurd and Kaneene, 1993

State transition models have a mathematical structure similar to a Markov chain, but one or more transition probabilities are not constant, and are defined as a function of the state of the system in the previous period of time. The basic assumptions of these types of models are that the period of infectiousness is constant, relatively short, and there is a constant probability of infection in each period of time. The most used model in this category is the Reed-Frost model, where the expected number of cases of the epidemic can be derived deterministically from the recursive formula:

$$C_{t+1} = S (1-q^{C_t})$$

where  $C$  is the number of cases at time  $t$ ,  $S$  is the number of susceptible individuals,  $q = 1 - p$ , and  $p$  is the probability of effective contact.

Carpenter (1988b) contains two epidemiological models, one modelled as a Markov process and the other as a state transition model. The Markov model evaluated multi-agent mastitis transmission and control alternatives in a dairy herd. The model assumed six states according to infection status, allowed for culling and restocking, and had constant transition probabilities. The second model was a modified version of the previous model. Culling and restocking were not allowed and the transition matrix was modified assuming that the number of animals infected with *Streptococcus agalactiae* at any time was dependent upon the number of animals infected with *Streptococcus agalactiae* during the previous period and the probability of avoiding effective contact in the Reed-Frost equation.

Carpenter (1988a) presents an epidemiological model based on the Reed-Frost model in which: i) the exposed population is vaccinated, ii) vaccine immunity wanes and is random, and iii) the number of effective contacts varies randomly among periods.

Using a state-transition model, de Jong and Diekmann (1992) derived an analytic expression for the basic reproduction ratio of the infection, i.e., the number of cases caused by one typical infectious animal. When this ratio is larger than 1, the infection can spread; when the ratio is smaller than 1 the infection will disappear. Therefore, a strategy for controlling an infective agent is effective only if it drives the ratio below one. The structure of the formula allows investigation of the influence of certain parameters (e.g., infection, demographic or control-strategy parameters) on the spread of an outbreak.

Garner (1992) describes a likely FMD outbreak based on various assumptions of how the disease may behave under Australian conditions; the effect of various factors on the course of an epidemic, and assessment of potential requirements of a vaccination strategy should this be considered are also examined. The model, a stochastic state-transition model, enables quantification of the effects of key variables of a FMD epidemic, including the effective contact rate that will apply, the delay between disease introduction and application of control measures, and the types and effectiveness of specific outbreak scenarios.

Cleland et al. (1994) analyzed immunity to FMD in Thai cattle and buffalo herds with a state transition model with two states (susceptible and immune); the main parameters were deaths, culling,

births and vaccination rates. A proportion of vaccinated animals lost immunity in the months separating vaccinations. The model was calibrated with data collected from 60 Thai villages. The main result is that to be effective, vaccination has to cover almost 100% of susceptible animals.

Other state transition models used to estimate the economic impact of FMD have been published; these are reviewed in the next section.

Hurd et al. (1993) present a stochastic distributed-delay model that can be used to represent both infectious and non-infectious diseases, and compares its behavior to a stochastic version of the Reed-Frost model for a hypothetical infectious disease. Both models produced similar results in terms of the average attack rates, and the bimodal distributions of total number of cases per epidemic. The shape of the distributions, though, was slightly different. Separation between the two peaks was not as great with the distributed delay model as with the Reed-Frost model. The tail was slightly more extended than the Reed-Frost, and there were more epidemics in the 50-100 case range.

Mortensen et al. (1994) used a meteorological dispersion model to analyze two outbreaks of Aujeszky's disease in Danish hog farms in regions known to be free from the disease. Their findings show that location, weather patterns and herd size are all statistically significant predictors of the hazard of infection. Herd size was also found to be positively correlated with the risk of infection by Willeberg et al. (1994). The factors mentioned as responsible for this size effect are:

- Direct effects of the number of animals on disease introduction,
- Spread and maintenance of infections within the herds,
- Different management in large and small herds,
- Misclassification of herd status when testing many animals.

The concentration of virus in the air is not homogeneous, and the amount of virus inhaled by animals can follow a Poisson distribution (Casal et al., 1997). As a result, even with low mean doses, some individual animals could have received a large enough dose to be infected. Under these assumptions, larger farms would have a higher probability of one animal receiving a dose large enough to become infected than smaller farms.

### **Models used to estimate the cost of a FMD outbreak**

The value of the losses caused by a FMD outbreak has four components: (1) the direct cost of dealing with the outbreak (cleaning and disinfection, compensation to producers, quarantine enforcement, etc.), (2) production losses, (3) induced price changes, and (4) the effect on other sectors of the economy. Different ways to estimate the value of losses have resulted in four methodologies: accounting methods, cost-benefit analysis, welfare analysis, and input-output (I/O) models.

Calculation of the first component is straightforward accounting. Estimation of the second component is usually done with an epidemiological model that estimates the physical production losses which are then converted to monetary values.

If the production losses are substantial or markets are disrupted by the outbreak, then both supply and demand of beef are affected resulting in a change in prices. In addition to domestic price changes, trade restrictions can reduce the price received for exports of animals and animal products. If prices rise, consumers will lose because they will have to pay more for their beef, while the loss to producers will fall because they will receive a higher price for their reduced output. The full value of price changes can be estimated with welfare analysis.

All production establishments purchase inputs and sell outputs from other economic agents (suppliers, workers, etc.). These agents, in turn, buy and sell products inducing additional economic activities that spread to the rest of the economy. Through these direct, indirect and induced linkages, a FMD outbreak not only affects the infected premises but the whole economy. Input-output (I/O) analysis estimates the direct and indirect cost of the outbreak to the whole economy.

The main limitation of welfare analysis is that it only considers price changes in a single market and does not include effects on other sectors of the economy. The main limitation of I/O analysis is that it does not include price effects. A problem shared by both methodologies is that they require large amounts of data. The selection of the methodology to be used should be based on the assessment of the relative importance of both effects, and on data availability.

Dufour and Moutou (1994) is an example of the accounting methodology. They estimated the direct costs of two alternative control strategies (i.e., annual vaccination and stamping-out) in France under the assumptions that i) both strategies are equally efficient in containing an outbreak and ii) the production losses incurred with both strategies would be equal. The direct cost of stamping-out is about 9% of the cost of annual vaccination. While the first strategy relies on the individual efforts by farmers (even though with a strong control by government veterinarians), the second strategy relies heavily on education, information and prevention by all parties involved in the livestock industry. Because of this shift in emphasis, the share of total costs borne by the state and local communities increases from 20% to 56% of the total costs.

Cost-benefit analysis considers not only the direct cost of an outbreak but also production losses over time. In some cases, it may include some losses to suppliers and customers of the affected sector and discrete changes in prices. The costs are the direct costs of the eradication campaign while the benefits are the losses avoided by using a particular control strategy. Both costs and benefits are calculated for a number of years and discounted to the present. This methodology is the easiest way to evaluate alternative control and eradication strategies. Its main drawbacks are that it does not consider the full price effects nor all the direct and indirect linkages.

Ellis (1994) details the basic procedures of cost benefit analysis and their application to evaluate FMD control strategies from the nation's and farmers' points of view. Van Ham (1994) estimated the damage to the Israeli dairy herd caused by FMD outbreaks and conducted a cost/benefit analysis of the present vaccination policy. The patterns of spread, the political situation at the borders, and the fact that the neighboring countries do not take adequate steps to eradicate the disease cause a FMD episode nearly yearly (64% of the last 22 years). The vaccination policy and other precautions keep the losses in Israel on a stationary level. A cost/benefit ratio of 46.5 was calculated by comparing the vaccination policy with the alternative of stamping-out without vaccination.

Andersson et al. (1997) use welfare analysis to analyze the social benefits of an eradication program of Aujeszky's disease in Sweden under three different policy regimes: government price support, internal market deregulation and EU-membership. The policy setting determines the magnitude and distribution of both benefits and costs. The total benefits of the program are evaluated across herd and size categories and different regions, consumers and the government.

Studies based on the welfare analysis have been widely used to analyze a large number of diseases. McCauley et al. (1979) estimated the economic costs of a FMD outbreak in the U.S. over a period of 15 years with several control strategies. One of the possible outcomes contemplated was FMD becoming endemic and vaccination used to reduce production losses. The outbreak was simulated with a state-transition model, that included four states (susceptible, infectious, immune and removed) and four strategies: (1) the current preventive policy of restricting imports of animals and animal products, (2) a stamp-out policy, (3) an area vaccination program aimed at achieving eradication, and (4) an endemic situation with two alternatives, compulsory vaccination program (under government control) and voluntary vaccination. The economic losses were estimated with an econometric model of the U.S. livestock industry. The model calculates the losses borne by consumers due to the reduced supply caused either by production losses or depopulation under the stamping-out policy. The main conclusions of the study are:

- If FMD is introduced into the U.S. and becomes endemic with only voluntary control (the benchmark policy), the discounted present value of losses over a 15 year period is estimated to be almost \$12 billion (at 1979 prices).
- The policy of restricting imports of animals and animal products has a benefit-cost ratio of 120 to 1 with respect to the benchmark.
- The stamping-out policy would be within limits of economic feasibility even if 1% of the national herd was slaughtered in the eradication effort. Such a massive eradication effort yields a benefit-cost ratio of 19.7 to 1.

Berentsen et al. (1990 and 1992b) developed an integrated approach to determine the economic consequences of alternative strategies to prevent and control FMD in the Netherlands. The approach

is based on a state-transition epidemiological model that determines the diffusion of FMD in Dutch herds under different preventive and control strategies, and an economic model that evaluates the social cost of each strategy. The model calculates separately the changes in consumer and producer surplus, and the budgetary cost to the government; particular attention is given to the consequences of FMD on beef exports. Separate calculations were made for three regions with different production conditions. Patrick and Vere (1994) apply a similar methodology to estimate the ex-ante benefits of an eradication campaign of Haemorrhagic Septicemia in Indonesia.

Dijkhuizen, Hardaker and Huirne (1994) evaluate several decision rules to show the impact of various risk attitudes of decision makers in determining what FMD control strategy to choose. Berentsen et al. (1992a) discuss the principles of cost-benefit analysis, stemming from neo-classical economic theory and welfare economics, and apply these principles to the analysis of an epidemic of a foreign disease in a beef exporting country. They analyze critically published cost-benefit analysis of FMD stressing the importance of producer and consumer surplus analysis.

Buhr et al. (1993) advocate the use of consumer and producer surplus to measure the total cost caused by an animal disease. The paper presents an econometric model containing lagged variables to estimate the supply and demand curves. Models that include lagged variables are reduced form specifications of structural dynamic models. The main problem of the proposed methodology is that consumer and producer surplus are well defined for static functions, but they have not been defined for dynamic specifications. An additional concern about this methodology when applied to FMD is that welfare measures are valid for marginal displacements of the supply and demand schedules. The cost of a FMD outbreak in a non-infected country, however, is likely to be very large.

Garner and Lack (1995) is an example of input-output analysis. They evaluate four control options (stamping-out, dangerous contacts slaughter, and early or late ring vaccination) for FMD in three different regions of Australia. A stochastic disease simulation model was used to generate outbreak scenarios, and an I/O model converted outbreak effects on farming and processing operations and subsequent effects of control programs into estimates of total economic impacts. The results show considerable regional variation according to ecological and productive conditions.

Krystynak and Charleboys (1987) does not belong to any of the four categories mentioned above. They used Agriculture Canada's Food and Agriculture Regional Model (FARM) to estimate the economic impact of trade embargoes that would follow a FMD outbreak in Canada. The FARM model is a large scale, multiple equation econometric model representing the economic relationships describing the Canadian agri-food system. Two scenarios, a small and a large outbreak, were simulated over a five year period; the epidemiology of the disease was not modelled and losses arise exclusively from trade disruptions caused by import bans imposed by importing countries. The results indicate that even a small FMD outbreak would have serious economic consequences for the livestock sector with farm cash receipts declining by \$2 billion (1987) Canadian dollars.

### **Other topics related to FMD**

Forbes et al. (1994) report the results of a workshop conducted in New Zealand to analyze the risk of introduction of FMD and assess the contingency plans to deal with an outbreak. The main concern of the participants was the lack of public awareness of the risks of the introduction of FMD by passengers arriving in New Zealand. Other factors mentioned were the tendency for commercial pressures to override technical standards, constraints in monitoring and surveillance services, the government's cost-recovery directives and weaknesses in the response program. Smuggled meat products were perceived to pose the greatest risk for the entry of FMD virus to New Zealand in the medium term, while a terrorist attack or criminal intent was perceived to pose the highest risk in the long term. The largest risk was perceived as coming from Asian-Pacific countries. The risk of a FMD outbreak was assessed as 1 chance in 50 years. As was the case with other countries, funding (both in levels as well as its variability) was one of the major concerns of the participants and was indicated as the most important factor affecting the effectiveness of the response to an outbreak.

A similar study is reported in Horst et al. (1996) for the EU. The relative importance of six risk factors concerning contagious animal diseases was estimated with conjoint analysis based on the opinion of expert respondents. FMD was one of the diseases included in the study and the risk factors considered were: imports of livestock, imports of animal products, feeding of swill, tourists, returning livestock trucks and airborne diffusion. Imports of livestock was ranked by respondents as being the largest risk of introduction of FMD, followed by imports of livestock products. The difference in the perceived relative importance of both risk factors was 43%. Garbage fed pigs were deemed as the third largest risk.

Donaldson and Doel (1994) analyze the new risks posed to the United Kingdom by the sanitary guidelines introduced by the EU in 1992 in the transition to an unified market. The elimination of FMD, the interruption of preventive vaccination in all member states and the adoption of a unified sanitary policy allow for increased trade opportunities. On the other hand, suspension of the vaccination will increase the risk of virus introductions. The main entry vectors to the UK would be live animals in which the disease is mild or asymptomatic (in particular, sheep and goats), and airborne diffusion originating in pig farms in Bretagne and areas of Benelux with high animal densities.

Maragon et al. (1994) report on the epidemiological investigation of the 1993 FMD epidemic in northern Italy. The livestock units are large (for European standards) and the cattle are permanently housed in covered yards. The Italian epidemic was the first to occur in the EU since the cessation of mass vaccination in 1991. The outbreak started in southern Italy; the source of the infection appears to be consignments of cattle imported from Eastern Europe and spread north through a lorry with infected cattle. As soon as FMD was confirmed in southern Italy, all movements of animals were traced and sanitary authorities in the north were alerted. Eradication of the outbreak was simplified by favorable atmospheric conditions, reduced contacts between herds and early detection. The area

at risk was delimited by the meteorological conditions using the model described in Moutou and Durand (1994) and the contacts between outbreaks. Delimitation of the high risk area with the meteorological model allowed to concentrate efforts in those areas where the infection risk was higher. In this epidemic, dangerous contact herds were slaughtered because they presented an unacceptable risk, particularly in the case of pig units.

Donaldson and Kihm (1996) reviewed recent advances in tests for the diagnosis of FMD, in addition to advances in surveillance, vaccinology and information technology, i.e., computing and networking. The first line of defense against FMD is the control of animal movements, especially imports. The tests used for screening animals must have a high degree of sensitivity and specificity to ensure that trade is not impeded but also to ensure that the indigenous population is protected. Tests can be for direct FMD virus or indirect serological tests. Recent advances in indirect tests have been in the direction of developing analyses based on monoclonal antibodies directed against a non-structural protein of the virus; such procedure would be serotype independent, thereby eliminating the need to test for antibodies against a range of serotypes. New progress in direct tests has been made in the development of immortalized bovine thyroid cells and this could be the basis of alternative direct tests for FMD. Another approach would be to test nasal swabs for the presence of viral RNA by the PCR method. Promising advances have also been made in detecting FMD antibodies in milk. Rapid recognition of a suspected case and speedy implementation of control measures are essential for the rapid eradication of the disease. The first contact with the disease will be by farmers and field veterinarians so it is essential that they are aware of the key features of the disease. Members of the National Veterinary Service should be trained in the contingency plans. A contingency plan should be created to secure full and speedy compensation to farmers when a stamping-out policy is applied. The use of modern computer based systems for management of FMD epidemics can greatly improve the efficiency of control and eradication strategies.

Lorenz (1986 and 1988) analyzed a number of FMD epidemics in non-protected populations of cattle and pigs in Europe between 1965 and 1982, and reported a highly skewed distribution of epidemic size with a range of 1 to 6,400 infected properties, a median of about 30 and a mean of 1,050. The majority of epidemics in unvaccinated populations involved less than 35 secondary properties, but occasionally a large epidemic was caused by a combination of factors favorable to the rapid and widespread dissemination of the virus through the animal population.

Saatkamp et al. (1994) and Saatkamp et al. (1997) report the results of an economic evaluation of four different identification and recording systems combined with two control strategies in contagious disease control in Belgium. The identification and recording methods analyzed are: 1) eartag identification and manual recording with documents; 2) eartag identification and manual recording with computerized data storage; 3) electronic identification using transponders and electronic data transfer and computerized data storage; and 4) as the previous system but with bio-sensors allowing

physiological monitoring of animals. The lowest control cost is achieved with the fourth system; the paper does not test, however, whether the system is economically viable given the greater cost of the transponders. The most important result, though, is the large reduction in the cost of an outbreak obtained when strategy 1 is replaced by strategy 2.

Callis (1996) reviews the risk posed by different traded commodities. Even though FMD virus has been found in bull semen, no outbreaks have been traced to exposure to infected semen even among animals that were never exposed to the virus. Many species can become carriers following infection, nonetheless the spread of FMD from carriers to susceptible animals has not been demonstrated. It is not recommended, though, that carriers be mixed with susceptible animals. Embryos from cattle, sheep and goats, when they have intact zona pellucida and when washed according to IETS recommendations, may be safely transferred from FMD-infected and recovered cattle without transmitting the infection. The FMD virus is inactivated in muscle within 24 to 72 hours after slaughter if the carcass is kept above freezing temperature, due to the reduced pH. In contrast, the virus may survive for weeks or months in refrigerated internal organs, bone marrow, lymph and haemal nodes, glands and residual blood. During infections large quantities of FMD virus may be found in milk some time before the development of clinical signs. Virus in milk disappears with the development of neutralizing antibodies. FMD virus in milk may survive both short and long pasteurization; either method reduces the titre of FMD virus significantly. Ultra-high temperature processing is sufficient to inactivate the virus. The virus survives the processing of casein or caseinates. FMD virus survives the processing of certain cheeses. However, the infectivity remaining after processing disappears with aging or ripening.

