Case study: Drainage and foot-and-mouth

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Abstract

Foot and mouth disease (FMD) is a severe, highly communicable viral disease of cloven footed animals. It can have devastating impacts on both livestock and national economies; the 2001 outbreak eventually cost the UK economy £8 billion. This paper examines the latest outbreak of FMD in 2007, which is thought to have originated from the drainage system of a research facility in Pirbright (Surrey, UK), and led to the infection of 8 nearby farms. The biosecurity arrangements associated with such facilities are examined, and the importance of an efficient and secure drainage system, to the overall level of biological containment, is highlighted. Information and data gathered from four comprehensive reports is used to illustrate the most probable sequence of events leading up to the outbreak. Finally, recommendations relating to the outbreak will be detailed and conclusions discussed.

Keywords

Drainage system; defects; extreme conditions; foot and mouth disease.

1 Introduction

Throughout the world, there are a number of government and privately run facilities that undertake research into various aspects of dangerous biological agents. In terms of animal-borne viruses, the potentially devastating consequences associated with FMD means that it is one of the most heavily researched of all biological agents. At each of the small number of facilities working with foot and mouth disease virus (FMDV), comprehensive biosecurity measures and procedures should be in place to prevent both inadvertent human exposure and the release of FMDV into the environment. However, such activities entail risk, and there have been 14 reported FMD outbreaks from research facilities since 1960[1].

The latest major global outbreak started in cattle at a farm in Surrey (UK) on 3rd August 2007. The initial outbreak quickly spread to infect an adjoining farm on 6th August, and is thought to have been the source for a second cluster of nearby cases between 11th and 30th September 2007 (see Figure 1). This outbreak necessitated the culling of 2160 animals (cattle, pigs, sheep, goats)[1], and resulted in a 4 month EU ban on the export of UK meat. By the time the UK was declared FMD free on 22nd February 2008, it is estimated that the total cost to the UK government and livestock industry was some £147 million[1].

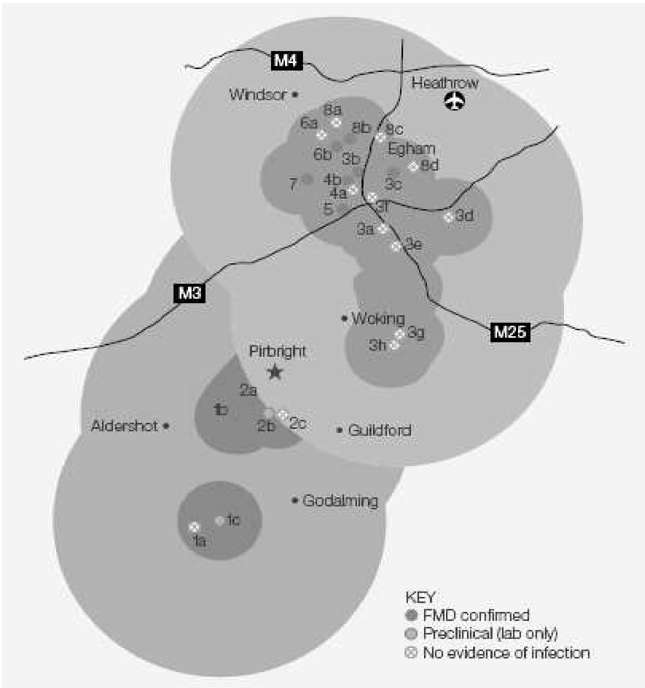


Figure 1: FMD clusters (source: Anderson report[1])

Laboratory testing indicated that the specific FMDV strain recovered from the outbreak was essentially identical to that recovered from the 1967 outbreak[2]. As this was not known to be in circulation anywhere in the world, initial suspicion for the source of the outbreak fell on the research laboratories at Pirbright in Surrey, which are the only known locations of this strain of FMDV in the UK. These laboratories are also located close to the infected farms.

1.1 Foot and mouth disease (FMD)

FMD is a severe, highly communicable viral disease of cloven footed animals, commonly affecting livestock such as cattle, swine, sheep and goats[3]; it can also affect wild animals such as deer. The disease can cause severe pain and lameness, often leading to a decrease in productivity, and can be fatal in young and weak adult animals. Although humans rarely become infected or develop the full blown clinical disease, they can carry the virus in their throats and noses for up to three days following exposure; in addition, clothing, footwear and vehicles have been implicated in a number of previous FMD outbreaks[3].

As FMDV can be present in animal secretions, including their breath, the most common route for infection is through direct contact with infected animals. However, the virus also survives well in various media, making delayed and wind driven transmission routes a real possibility; FMDV lifespan ranges from 3 days in summer soil to 180 days in slurry[2]. Only a small infective dose is normally required (as few as 10 virus particles being sufficient to infect a cow[3]), and there is hence a rapid rate of progression.

1.2 Biosafety and biosecurity

The terms biosafety and biosecurity mean many different things to many different people and organisations. Within the context of the laboratory handling of animal pathogens, such as FMDV, these terms are defined by the WHO[4] as:

> *"Biosafety describes the containment principles, technologies and practices that are implemented to prevent the unintentional exposure to pathogens and toxins or their accidental release."*
>
> *"Biosecurity describes the protection control and accountability for valuable biological materials (including pathogens and toxins) within laboratories in order to prevent their unauthorised access, loss, theft, misuse, diversion or intentional release."*

In order to work with FMDV in the UK, an organisation requires a licence from the Department of Environment, Farming and Rural Affairs (Defra) under the *Specified Animal Pathogens Order (SAPO)*[5]. The purpose of SAPO is to prevent the introduction and spread of animal pathogens that could cause serious disease and/or significant economic loss to the British farming industry. This is achieved by careful control of biosafety and biosecurity, with SAPO specifying 4 different levels of containment; facilities handling FMDV require the highest SAPO level 4 containment level. In order to achieve secure containment, it is common to utilise a system of barriers[2].

- Primary barrier, which is closest to the biological agents and prevents direct exposure (e.g. culture vessel).
- Secondary barrier, which prevents release of 'live' pathogens to the exterior environment (e.g. walls, waste treatment system).
- Tertiary barrier, which prevents unauthorised entry to site (e.g. perimeter fencing).

2 Pirbright research facility

2.1 Overview of site

The Pirbright site is owned by the Biotechnology and Biological Sciences Research Council (BBSRC) and is the foremost facility in the UK for both research into FMDV and for production of FMD vaccine. There are essentially three different organisations based at Pirbright, each of which hold SAPO 4 licences and work with FMDV.

- Institute for Animal Health (IAH) is a publicly funded organisation that undertakes research into FMDV and its effects. IAH also undertakes diagnostic work to identify and catalogue the various different FMDV strains.
- Merial Animal Health (MAH) is part of a global, commercial pharmaceutical company. Its activities at Pirbright are related to the manufacture of vaccines for a range of animal diseases, including FMD. MAH leases their site from BBSRC.
- Stabilitech Limited (SL) is a small commercial company involved in the development of technologies to ensure effective storage of vaccines and other biological materials. SL rent laboratory space from IAH.

Although the work undertaken at Pirbright is potentially hazardous, and is certainly vital to the British nation, it is commonly accepted that the current state of facilities is not up to accepted international standards[2,3]. As a result of these concerns a £121 million redevelopment of the site was agreed in 2005, although new laboratories are not due for completion until approximately 2012[2].

2.2 Pirbright laboratory drainage and treatment

Each of the organisations at Pirbright produce FMDV to support their work; IAH and SL require only small quantities of the virus for their research activities, whilst MAH produce FMDV on an industrial scale for vaccine production purposes. Irrespective of the FMDV quantities involved, all laboratory waste undergoes chemical treatment prior to entering the main site drainage system. Although this treatment is intended to be 100% effective, it appears that live FMDV may well enter the site drainage system on occasions[3]. In fact, the MAH site director estimates that 0.01% of FMDV may still be alive after treatment, equating to ~ 1 billion infectious units in a normal production batch[2]; interestingly, the biological safety officer at IAH appears to have been unaware that such large quantities of live FMDV may be entering the site drainage system from MAH laboratories[2]. Indirect waste from each of the facilities, such as that from showers and toilets, is not treated prior to entering the site drainage system. These general procedures have been approved by Defra.

Figure 2 shows a schematic view of the main site drainage system, which exhibits the following characteristics:

- The foul drainage has been constructed in phases, and comprises of predominantly vitreous clay pipework, with some cast iron and UPVC. Older pipework tends to be 4" (100mm), whilst newer pipework tends to be 6" (150mm).
- IAH and SL waste is discharged via gravity mains, whilst MAH waste is discharged via a sump and a pump main (served by two pumps).
- All waste undergoes secondary treatment at a caustic soda plant (~50 years old). It is then held in storage tanks, until its pH is below 11, before being discharged to the main sewer where it undergoes final treatment at Hockford sewage treatment works.
- Surface water from IAH and SL areas is stored in buried open-topped tanks, with overflows to a small lagoon, and eventually discharged into the Stanford Brook. That from MAH area is discharged directly to the public sewer.

3 Outbreak

As detailed previously, the initial outbreak occurred in cattle at a farm in Surrey on 3rd August 2007, and quickly spread to an adjoining farm and a second cluster of cases. Although laboratory testing indicated that the FMDV probably originated from the Pirbright site, the minor genetic modifications that occur rapidly following release meant it was not possible to pinpoint exactly which of three facilities was responsible.

Evidence collected from a number of different investigations highlighted that the most probable sequence of events that lead to the outbreak had four stages:
- Establishment of necessary conditions.
- Release of FMDV from containment facilities.
- Transmission of FMDV from Pirbright site.
- Infection of farms.

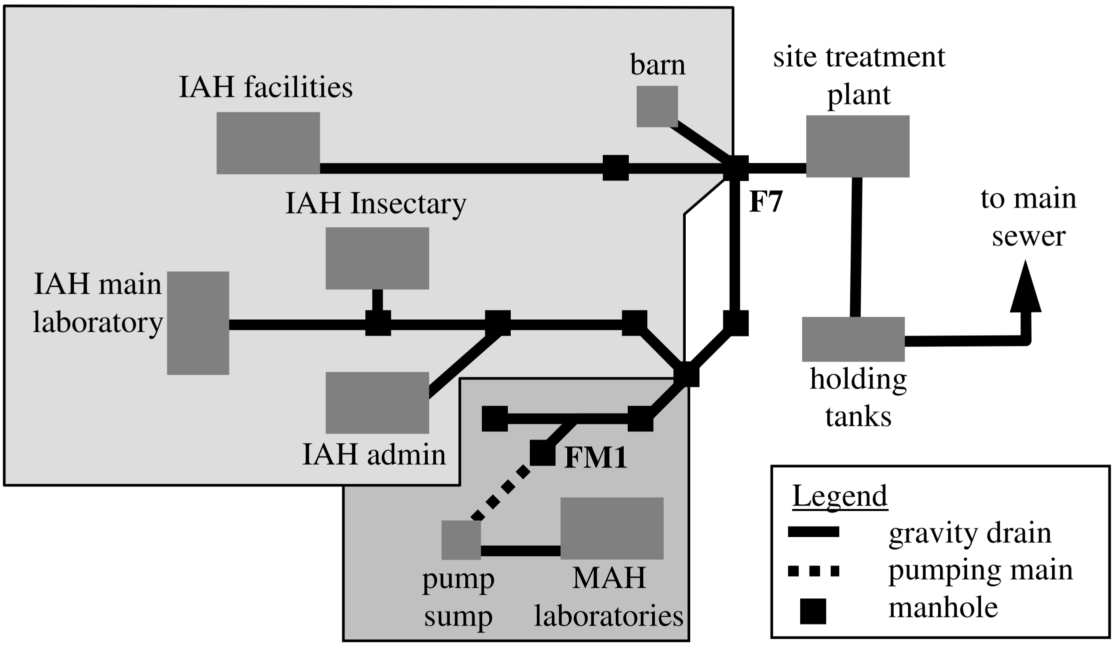


Figure 2: Pirbright site drainage system

It should be noted that the description of the outbreak herein makes extensive use of words such as "probable" and "likely". This is because, despite extensive investigation, it has not been possible to *categorically* state how the FMD outbreak was initiated or spread; rather the description herein represents, on the balance of the evidence, the most probable or likely sequence of key events.

3.1 Establishment of necessary conditions

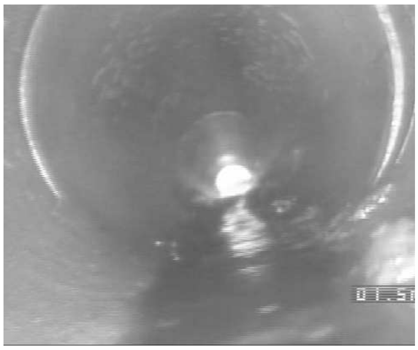
The establishment of the conditions necessary for the outbreak itself comprised of four elements, namely: weather conditions, FMDV virus production, site drainage condition and site construction activities. The prevailing weather conditions in the weeks leading up to the initial outbreak were extreme. Up to 62mm of rainfall was measured in the locality on 20th July, which resulted in localised flooding in and around the Pirbright site, with both standing water and high groundwater levels being observed until 23 July[3]. Although the site drainage system was thought to be full (though not overflowing), water was seen to enter the caustic soda treatment plant; this resulted in an agreed temporary reduction in waste discharges to the site drainage system[2].

Immediately preceding this period of extreme weather, MAH produced two significant batches of FMDV (6000l each). Waste from the cleaning of the production vessels was discharged to the site drainage system on 20th July, whilst the *theoretically dead* FMDV waste itself was discharged between 22nd - 23rd July and 25th - 26th July. Within the same time frame, both IAH and SL produced negligible quantities of FMDV.

Although the general state of the site infrastructure had long been known to be substandard, the extremely poor state of the site drainage system only truly became apparently as a result of the investigations following the FMD outbreak. In particular, inspection of the drainage system (physical surveys, CCTV surveys, documentation review) highlighted the following key defects[3]:

- General structure not well understood.
- Poorly fitting manhole covers and damaged chambers (see Figure 3a).
- Cracks and displaced joints (see Figure 3b).
- Debris accumulation and tree root ingress.
- Evidence of water ingress at pipe crowns.
- Permanent standing water in some sections.
- Dead legs associated with decommissioned facilities.
- Evidence of repeated blockage and surcharging.
- Number of recent breakdowns of final treatment plant (e.g. valve failure).
- Evidence that foul flows have entered surface water lagoon.
- Unsatisfactory maintenance/inspection procedures, including no routine testing of discharges.

a. Damaged manhole joints



b. Joint misalignment and crack

Figure 3: Examples of drainage system defects (source: HSE report[3])

As part of the site redevelopment scheme, a variety of different construction activities were being undertaken in the period preceding the initial outbreak (14th - 26th July). These included the excavation of new manholes and inspection trenches, the widening of existing site roads and the construction of new roads. Some of these works were located in close proximity to the MAH pump sump, whilst others crossed directly over drains leading from IAH laboratories. Excavated material was either left in spoil heaps on site, or transferred to an off site disposal facility.

3.2 Release of FMDV from containment facilities

Investigations concluded that there was negligible likelihood that FMDV was released from the containment facilities by either airborne or human transmission, or through solid waste disposal. In the absence of any other credible routes, it was therefore concluded that FMDV was probably released from the liquid waste system (i.e. the site drainage system). Given that only MAH discharged substantial quantities of FMDV waste to the drainage system immediately preceding the FMD outbreak (20th – 26th July), it is thought likely that the MAH laboratories were the source of the virus release. It should be recalled that up to ~ 1 billion infectious FMDV units may survive initial laboratory chemical treatment from a normal production batch[2], and only 10 units are required to infect a cow[3].

The drainage surveys identified that, of the many areas of concern, the section between manholes FM1 and F7 (see Figure 2) was the critical section; this portion of the system exhibited many different defects and also conveyed the greatest discharge. Within this section, manhole FM1 was highlighted to be of particular concern as it was:

- Located immediately downstream of the pump main from the MAH sump
- Connected to a short, near vertical connection to downstream pipework, hence increasing the likelihood of turbulent flow conditions and system surcharging.
- Shallow (300mm).
- Not air or water tight (poor fitting cover, evidence of tree root ingress).

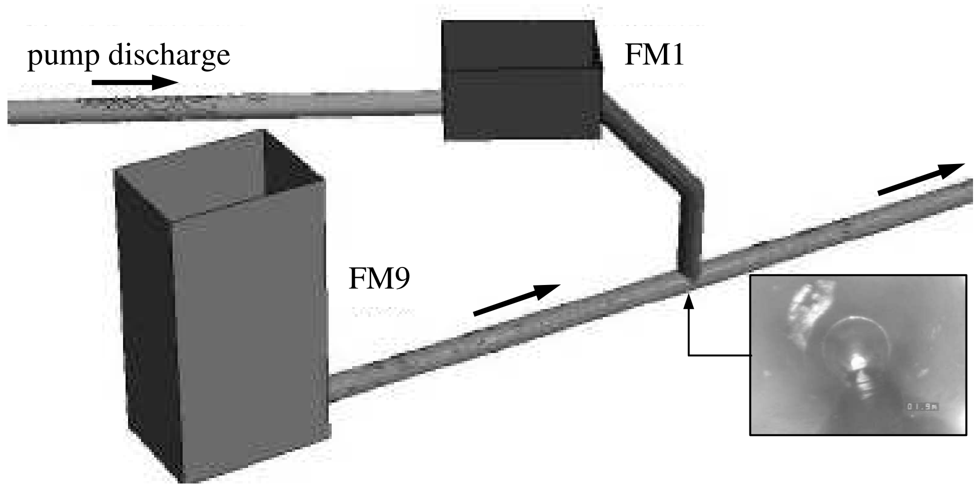


Figure 4: CFD model and photograph of pipe configuration in vicinity of FM1 (source: HSE report[3])

CFD analysis was undertaken to determine the flow conditions in the vicinity of manhole FM1 under a variety of different pump loading conditions (see Figure 4). The results indicated that, with one of the pumps operating (6.95 l/s), FM1 was predicted to overflow only if there were a significant blockage in the downstream system; the physical surveys suggest that this could be a common occurrence. With both pumps operating (13.9 l/s), the unorthodox pipe arrangement meant that FM1 was predicted to overflow even without a system blockage. Although the results of such analysis must be treated with caution, anecdotal evidence tends to support these findings (e.g. some backup into FM1 is often observed during normal pumping operations[3]).

The CFD analysis and survey results indicate that the release mechanism from the site drainage system was most probably due to overflowing of manhole FM1 or from general pipe leakage at some point in the system (perhaps for extended period of months or years). It should be recalled that FMDV can live for up to 3 days in dry summer soil, and much longer in the type of saturated conditions that preceded the initial outbreak.

3.3 Transmission of FMDV from Pirbright site

After determining the probable cause of the FMDV release from the containment facilities, it was necessary to determine how the virus was transmitted to the locality of the infected farms. Although the whole region was affected by flooding at the time, the general topography (Pirbright is 5-10m below the elevation of the first infected farm) and natural flow lines meant that it was "practically impossible" that transmission occurred via overland flooding[2]. Investigations also concluded that it was highly unlikely that FMDV transmission was via the normal sewage system, wild animal activity or human activity (disgruntled staff, terrorists, etc). Therefore, attention turned to site construction activities.

As noted previously, there were significant groundworks during the period 14th – 26th July, which overlaps with the probable period during which FMDV was released from the drainage system (20th – 26th July). During this timeframe, approximately 1000 vehicles visited the site, some of which were 32 tonne trucks transporting excavated soil off site. These activities necessitated the trucks being in close proximity to the existing drainage system and/or in contact with soft soil near access roads. It was therefore concluded that construction activities probably led to disturbance of subsoil that had been contaminated with FMDV from the defective drainage system. As such it was concluded that construction traffic probably formed the transmission route for FMDV off the Pirbright site; it is thought that either the actual truck loads contained contaminated subsoil or the truck wheels/wheel arches picked up and transported contaminated subsoil.

3.4 Infection of farms

Although construction traffic had been highlighted as the most probable transmission route for the FMDV from the Pirbright site, none of the trucks actually had direct contact with the infected farms. However, between 20th – 25th July, six uncovered trucks left the site to take excavated subsoil to Compton landfill site. The route travelled by these trucks passed along Westwood Lane, which is adjacent to the fields of the first infected farm and is used by the farmer for access. Given the coincidental dates, it is considered most likely that contaminated subsoil from one or more of the trucks was deposited along Westwood Lane, and was then picked up by the farmer and taken into his fields, where it caused the initial FMD outbreak; an alternative theory is that contaminated subsoil fell from one of the lorries directly into the fields. It was therefore concluded that the initial farm outbreaks were caused by cross-contamination of the farmers vehicles by subsoil from construction traffic. Although no definitive explanation has been forwarded to explain the subsequent outbreaks, they were to be expected given the close proximity of the later outbreaks to the first infected farm.

4 Compliance with standards

In assessing whether the facilities at Pirbright comply with standards, it is instructive to recall the system of barriers that normally constitute suitable containment (see Section 1.2); in particular, all biological agents should be made safe before exiting the secondary barrier. As the laboratory waste treatment procedures are known not to be 100% effective, this essentially means that the site drainage system actually forms part of the secondary barrier, and should hence prevent release of biological agents to the exterior environment. This principle is confirmed by SAPO licensing authority (Defra), who have commented that drainage systems associated with SAPO licensed facilities should comply with the same containment requirements as the laboratories themselves[3]. Given these principles, it is clear that the Pirbright site drainage system does not comply with fundamental standards of containment, as is not:

- Demonstrably leak proof.
- Airtight, or negatively pressured.
- Proofed against ingress and egress of insects.
- Isolated from flooding.

Furthermore, the extensive surveys of the Pirbright site drainage system also indicate that it does not meet British Standards for workmanship for below ground drainage[6], and would be unlikely to pass standard pipe soundness testing[7]. Consideration of these issues leads to the conclusion that the existing site drainage system does not meet necessary containment standards for a biosecurity critical system. This is primarily due to poor maintenance, poor monitoring and poor record keeping over an extended period of time.

5 Recommendations and actions

The UK government accepted all of the specific recommendations made by the two main reports into the FMD outbreak[8], including the need for:

- Improvements to the site drainage system to ensure full containment (infrastructure, maintenance, monitoring, records).
  - Pending construction of a new system, existing pipework has been relined, manhole covers sealed and dead legs blocked off to ensure containment.
  - In the interim, all FMDV waste must be completely inactivated prior to discharge.
- Improved waste treatment procedures to minimise discharge of live FMDV to site drainage system.
- Improved clarity of biosecurity regulations and responsibilities.

- Improved communication between IAH and MAH biological safety officers, particularly concerning the shared site drainage system.
- Improved control and monitoring of access to site.
- Widespread circulation of the report findings to facilities involved with similar pathogens.

In addition to the above, the Callaghan review[9] recommended that responsibility for inspection and enforcement functions (concerning animal pathogens) pass to a body that is not subject to conflict of interest and has the requisite technical expertise; at present Defra is a "major customer of animal pathogens research and diagnostics at Pirbright", as well as being the regulator, licensor and inspector of such facilities.

6 Conclusions

The complexity of the events that surrounded the FMD outbreak effectively means that no one can be 100% certain of the precise cause. However, the extensive investigations that were undertaken do indicate that the most probable explanation involved 4 key stages, namely: the release of live FMDV to the site drainage system (due to ineffective waste treatment), the release of live FMDV to the Pirbright site (due to defective drainage system), the transmission of live FMDV from the Pirbright site (due to construction traffic) and the initial farm infection (due to cross-contamination of vehicles). In common with similar events, the FMD outbreak occurred due to a sequence of critical events rather than one individual cause; for example, irrespective of the effectiveness of the laboratory waste treatment system, the outbreak would probably not have occurred if the drainage system had been sound. The outbreak may therefore be viewed by some as a fluke occurrence. However, the dilapidated state of the site infrastructure, particularly the site drainage system, indicate serious systematic problems. Equally worrying is the apparent absence of regular dialogue/understanding between the main organisations regarding biosecurity; this is best epitomised by the lack of clarity concerning live FMDV discharges to the site drainage system.

Although the site redevelopment scheme should deliver improved laboratory waste treatment facilities, it is clear that there will always be the possibility of future releases of live FMDV to the site drainage system. It is therefore vital that, as recognised by all parties, the drainage system is considered an integral element of the overall containment system; as such, its design and maintenance must comply with relevant standards.

In addition to highlighting the importance of effective waste treatment and drainage infrastructure, this case study has emphasised the importance of effective communication when dealing with complex systems, particularly those involving multi-user systems. It has also highlighted the need for stringent regulatory control of sensitive national facilities. In this respect it is perhaps surprising that the maximum penalty for breaching the terms of a SAPO licence is £5000[1]. It is also surprising to learn that live FMDV was released from MAH laboratories into the Pirbright site drainage system on 19th November 2007, just 13 days after their SAPO licence had been reissued; although the leak was contained and no damage was done, IAH claim that they did not know that MAH had resumed vaccine production[1].

Acknowledgements

This report has drawn heavily on the formal investigations that followed the FMD outbreak, including:

- *Independent Review of the safety of UK facilities handling foot-and-mouth disease virus.*
- *Foot and Mouth Disease 2007: A Review and Lessons Learned.*
- *Final report on potential breaches of biosecurity at the Pirbright site 2007.*
- *A review of the Regulatory Framework for Handling Animal Pathogens.*

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Presentation of Author

Grant Wright is an academic fellow within the School of the Built Environment at Heriot-Watt University. Wright specialises in the numerical simulation of unsteady flows within piped drainage systems, particularly those associated with mixed free-surface/full-bore flows within roof and local drainage systems.