ASSESSMENT OF THE HAZARDS AND RISKS ASSOCIATED WITH THE SOUFRIERE HILLS VOLCANO, MONTSERRAT

Sixth Report of the Scientific Advisory Committee on Montserrat Volcanic Activity

Based on a meeting held between 27 and 29 March 2006 at the Montserrat Volcano Observatory, Montserrat

Part I: Main Report

Issued 21 April 2006

Summary

(i) Since October 2005 the lava dome has grown rapidly, after a slow start during the first two months of extrusion. It has now almost reached the rim of the crater on the northern and western sides and the dome summit is once again the highest point on the island. The rate of extrusion accelerated from about one cubic metre per second to about three to four cubic metres per second in mid-December 2005. By mid-February 2006 the rate had reached a peak of about sixteen cubic metres per second, as high as anything measured in the whole eruption. The rate has since fallen to about two cubic metres per second.

(ii) The new andesite lava is of similar composition to that previously erupted. The dome has grown by a mixture of internal swelling and external summit extrusion, including spines, in a similar manner to that seen in earlier episodes. However, there have been no significant explosions nor major collapse events of the dome so far, and the pyroclastic flows formed from the smaller collapses have not been very mobile. These characteristics could be explained if the lava is arriving at the surface with lower gas pressures than previously. Such a trend could reduce the hazards, if confirmed.

(iii) Now that the dome has grown close to the crater rim, there is the renewed possibility of dome collapse events forming pyroclastic flows outside the crater into Gage's Valley and Tyer's Ghaut. At the moment this is not likely, but another period of high extrusion rate to the north or west could generate dangerous flows within days of a switch in eruption point. On the other hand, reduction of the accumulated dome volume by collapses into Tar River, as has happened many times before, could moderate this threat. As a result, the risk to occupied Montserrat generally has increased marginally. However, collapses of only modest size into Gage's Valley could threaten people working in Plymouth. A similar but lesser risk applies to the Belham River area.

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Introduction

1. The sixth meeting of the Scientific Advisory Committee (SAC) on Montserrat Volcanic Activity took place at the Montserrat Volcano Observatory (MVO) from 27 to 29 March 2006. This report is the main product of that meeting. The Committee was commissioned by the Foreign and Commonwealth Office and operates under the Code of Practice for Scientific Advisory Committees issued by the Office of Science and Technology. The Terms of Reference for the Committee are presented in Appendix 1, and the agenda of the meeting is given in Appendix 2.

2. The meeting was attended by: Professor G. Wadge (SAC Chairman), Dr. W.P. Aspinall (SAC), Professor K. Cashman (SAC), Mr. T. Christopher (MVO), Dr. V. Hards (MVO), Dr. S. Loughlin (MVO), Dr. R. Luckett (MVO), Prof. J. Neuberg (SAC), Dr. R. Robertson (SAC), Dr. G. Ryan (MVO), Mr. M. Strutt (MVO) and Professor B. Voight (SAC). Mr. T. Syers (MVO) was present for part of the first day. Appendix 3 gives a list of participants and their affiliations.

3. This report is largely concerned with the risks posed over the next year by the growing lava dome, particularly to Plymouth and the Belham Valley. In addition, with the advent of Professor Cashman to the SAC, we refocused our interest on the composition of the lavas and what that can tell us about processes occurring in the magma reservoir. In mid-February 2006 the rate of growth of the lava dome on the northwestern side of the crater was very high, causing concern to MVO and government. The SAC was asked for an interim assessment of the risks posed, particularly to worker and visitors to Plymouth. That assessment is presented here as Appendix 5.

4. In anticipation of the end of the current five year MVO management contract we were asked to suggest terms of reference for a Scientific and Management Audit of MVO and suggest how this might be undertaken. Those draft terms of reference form Appendix 6.

5. There are two parts to this report: Part I contains the main findings and Part II contains the technical aspects of the assessment. Appendix 7 has a glossary of technical terms. A Preliminary Statement (Appendix 4) from the meeting was issued on 29 March 2006. An interview with Wadge that discussed some of the preliminary findings of the risk assessment meeting was broadcast on ZJB Radio that same day. A three-hour public meeting was held that evening at Brades to explain the preliminary findings to the public, also broadcast by ZJB. Several

people expressed the wish to have government representation present at such meetings in future.

Recent Volcanic Activity

6. In the October 2005 report we noted the relatively slow start during the first two months of renewed dome extrusion. In the intervening six months the rate of extrusion increased considerably and the dome grew rapidly to a volume of at least 55 million cubic metres by the end of March 2006. Although the dome has grown faster over the same interval than the domes that grew in 1995-1996 and 1999-2000, it has done so without explosions or collapses.

7. Until the end of October 2005 the growth of the dome was constrained by the transverse ridge of pre-2003 dome rock running across the crater. At this time the extrusion rate had risen from its earlier values to about 1 cubic metre per second. During November 2005 this ridge was buried by new lava and a large talus apron began to develop beyond it to the east. The style of growth changed from internal expansion to external asymmetric flow as “shear lobes”. The rate of extrusion increased yet again in the second half of December to 3-4 cubic metres per second. The top of the dome was over 800 m above sea level (asl) at this time, about 120 m above its base. By 11 January 2006 the style of extrusion changed to that of a flat topped flow lobe moving from west to east across the summit of the dome.

8. On 7 February 2006, following a series of earthquakes, the rate of extrusion seems to have fallen to very low levels, perhaps even stopped. On 9 February, following a swarm of long period earthquakes, a north-northeast oriented fissure opened to the west of the dome summit with vigorous steam venting , and ash and rocks being forcefully ejected. This brief disruption of an otherwise vigorous period of extrusion seems to have involved the formation, or re-opening, of northerly fractures away from the conduit that may have included groundwater-magma interaction. By 11 February this fissure had become the source of a new flat-topped or “pancake lobe” lava extrusion that, as in January, moved from west to east at a very high rate of growth. Over the next two weeks the extrusion rate may have been as high as 16 cubic metres per second. By the end of February the dome stood nearly 280 m above its base at an altitude of 960 m above sea level; the volume of the dome having doubled during that month. Much of the new volume added in mid-February was on the northern side of the dome where it accumulated and nearly overtopped the crater rim above both Gage’s and Farrell’s Walls.

9. A large diameter (~50 m) summit spine grew on 26 February with a reduction of extrusion rate. By mid-March the direction of dome growth shifted to the east and southeast, and the immediate danger to the north and west was relieved. The rate of extrusion during March seems to have fallen to about 2 cubic metres per second.

10. So far, dome growth has been concentrated on the northern half of the crater, with less growth on the south side against the Galway's Wall. The topography of the eastern part of the crater now tends to force any pyroclastic flows onto the southern wall in a narrower pathway than in previous times. However, there have been relatively few pyroclastic flows during this episode (the first one, on 15 November 2005, was sampled) and they have had weakly convective ash clouds associated with them, and short run-outs (less than 2-3 km). It may be that the dome lavas are less gas-rich or pressurised than they have been in the past. The presence of the buried transverse ridge east of the conduit may inhibit deep retrogressive collapses. Both of these factors may mean that future major collapse events during this episode could be less common than previously.

Monitoring Data

11. This third episode of lava extrusion has so far seen very few earthquakes originating by rock fracture. This is probably because the conduit is relatively "open". Most of the recorded events are either of long-period type, indicative of gas or fluid flow, or caused by rockfalls from the unstable dome. Both of these increased significantly during mid-October. For 22 hours prior to the noisyventing that occurred on 10 February, a distinct period of tremor with a 4-hour banding was recorded. These vents may have used the same fractures that are inferred to have been created or re-activated in April and June 2005.

12. There is now a more convincing set of signals from the cGPS data that display shortening of the baselines between stations which are indicative of general deflation of the volcano, in response to the large amounts of magma being evacuated from the reservoir. An inflection from extensional to contractional (shortening) strain occurred in December 2005, at a time of rapid increase in extrusion rate. However, caution is required when interpreting this change in that a semi-annual island-wide signal, perhaps caused by the hydrological cycle, may also affect the cGPS data: as a consequence, the longer-term trend may only appear clearly over several such cycles. EDM measurements to Hermitage from Jack Boy Hill and Spanish Point show general extension until late 2005, but contraction and no change respectively since. These trends reinforce the cGPS

results and show that at the moment the Hermitage site motion does not appear to be anomalous relative to the other cGPS stations.The Windy Hill to Farrell's Wall EDM line shows no change over this period, indicating a stable Farrell's Wall.

13. Sulphur dioxide emission rates in this period have remained close to, but slightly above, the long-term 500 tonnes per day average. The expected increase in the emission of hydrogen chloride, as measured by the hydrogen chloride-sulphur dioxide ratio has occurred. The ratio rose from just below 1 in September 2005 to 2 – 3 in February and March 2006, with a peak of 3.8. Although measurements of hydrogen chloride are relatively sparse compared with those for sulphur dioxide, it is clear that there was no precursory signal of elevated hydrogen chloride prior to dome extrusion. However, hydrogen chloride measurements may be of use as a proxy for the rate of lava extrusion.

14. As we anticipated in the last SAC report, the ground-level concentrations of volcanic gases measured by diffusion tubes around the Plymouth area have fallen considerably now that the new lava dome is well-established. However, they have not yet fallen to values as low as in 2000.

15. A sample from the 15 November 2005 lava has been analysed petrographically. It is an andesite, very similar to the typical rocks extruded in the last two episodes. The amphibole, orthopyroxene, plagioclase and iron oxide minerals all show signs of re-heating, which may be related to the influx of basalt in the reservoir or a later release of latent heat.

Probable Future Behaviour

16. It is now almost certain that a third major episode of dome extrusion, comparable in volume and duration to the two previous two episodes, is underway. Six months ago when the average extrusion rate was less than one cubic metre per second, we considered the possibility that this third episode might have a lower average extrusion rate, with any short duration, peak events also having reduced maximum extrusion rates. So far neither of these has proven to be the case. We think the present extrusive episode may continue for about another two years or so. Thus the extrusive vigour of this third episode seems to be no less than the previous two. However, there is one trend that may prove to be significant. The lack of any explosions or major collapses so far, together with the relatively weak mobility of the pyroclastic flows in the Tar River Valley, suggests that the lava may be relatively more degassed on reaching the dome than in previous episodes. This could be happening because of processes in the magma reservoir or because of

reduced speeds of magma rise in the upper conduit due to an increased diameter. If this does prove to be the case then it may be that the likelihood of future hazardous behaviour will be reduced.

17. This eruption of Soufrière Hills Volcano has been going on for almost eleven years and is one of the longest in the historical record for volcanoes of this general type. Based on rather limited data from similar volcanoes worldwide we find that the probability of the continuation of the eruption for another five years, perhaps with further pauses, is about 80% and for another twenty years is almost 50%.

Assessment of Volcanic Hazards

18. The resumption of vigorous dome growth in the last six months, together with the large size of the dome, means that the threat of hazardous activity has risen since the last report. The types of hazard remain the same: dome collapse pyroclastic flows, rock avalanches, explosion-derived rock fall, and column collapse pyroclastic flows.

19. Because of the growing concern of collapses down the Gage's Valley and Tyer's Ghaut and into the Belham Valley, we focused our attention on flows down these valleys under scenarios of day workers in Plymouth and inhabitants of the former DTEZ.

20. The current dome has grown very quickly in volume and height. Between December 2005 and February 2006 it grew faster than at any time in the entire eruption. Also, it has grown particularly in the northwestern part of the crater, where the potential hazard to occupied areas from collapses overtopping the crater walls is most acute. That said, a period of growth over several months to the south and east could add a further significant volume to the dome within the crater without increasing the hazard to the north and west. Also, at the current average rate of growth for this episode it would take about another 20 months to reach the volume of the dome at the end of 2002, during the second episode of dome growth. However, as we have seen in February 2006, the dome can grow very fast for short periods in directions with a propensity for collapse to the north and west. It is the future likelihood of such a scenario that we take into particular account in our assessment.

21. The dome lava now rests a few metres below the crater rim above the Gage's and the western Farrell's Walls. The situation at Gage's Wall is complicated by the remnant "Northwest Buttress" of old dome lava. This will both prevent some new

lava from spilling down into the Gage's Valley but, if sufficiently stressed by lava pressing on to it from behind, it could also now fail outwards and produce a rock avalanche. Such an avalanche could reach Plymouth. There is no such mass to fail on the Farrell's Wall and there are no indications of current structural weakness there.

22. Even when the western crater rim above Gage's Wall is overtopped by new dome lava there is no automatic triggering of collapses in Gage's Valley. As we saw in 2002, a wedge of talus can build out for many months without failing. However, the key factors are the volume of dome above the crater rim at the time of any (rapid) loading of the west- facing sectors of the dome by new lava lobes. We judge that a collapse of about two million cubic metres or more down the Gage's Valley would be sufficient for flows to reach Plymouth. Collapses of this scale have not occurred down Gage's Valley since late 1997.

23. Similarly, we estimate that when the northern rim of the crater at Farrell's Wall is overtopped a collapse of about five million cubic metres would be required to reach the Weeke's/Cork Hill part of the Belham Valley via Tyer's Ghaut, and a volume of more than ten million cubic metres would be needed to reach the sea at Old Road Bay. Collapses down Tyer's Ghaut have been much smaller than the above figures, and there is currently not enough volume available to generate such collapses.

Assessment of Risks to People

24. As in previous reports we take each hazardous process identified above, estimate the probability that they will occur and affect a given area of Montserrat and then calculate quantitatively the risk to which a given number of people in that area will be exposed. We use the UK Chief Medical Officer's (CMO) scale (Appendix 7) to convey a qualitative description of the scale of the risk based on the numerical estimates. Details of the probability and risk calculations are presented in Part II of this report. These risk estimates have large uncertainties and so the reader should not attribute detailed meaning to small numerical differences in these values. The descriptive CMO scale categories, as reported here, better capture these differences.

25. During the last few months, the overall risk to the people of Montserrat from the Soufrière Hills Volcano has risen slightly and is poised to rise further because the hazards from lava dome collapse have once more started to come into play. The risks in the Exclusion Zone around Plymouth and also in the former DTEZ are

elevated mainly because of the threat of pyroclastic flows down the Gage's Valley and Tyer's Ghaut. We stress that the risk to people in the north of the island is negligible.

26. *Risks in the Lower Belham Valley and former DTEZ areas*

Given dome growth has not yet reached the point when over-topping the crater is taking place (and currently is proceeding at a reduced extrusion rate in the eastern part of the crater), the most immediate hazards to people residing or working in the Lower Belham Valley and former DTEZ (including Isles Bay, and Friths/Happy Hill/Old Towne south) could come from: a) small to moderate explosions with fallout of rocks and ash, and b) larger explosions with accompanying pyroclastic flows generated by column collapse. The hazards from fallout of rocks could occur anywhere across these areas, and can be mapped from simulation models. The hazards from column collapse pyroclastic flows and surges would be concentrated in areas abutting flowpaths coming from Gage's Valley, and, marginally, in the Belham Valley near Cork Hill. With current conditions, the individual risk exposure for people residing in these areas is assessed LOW on the CMO's scale. However, the risk could rapidly move into the MODERATE category if there is a switch to higher rates of magma flux or if dome growth becomes re-focused towards the northwest.

27. *Other occupied areas*

In the adjoining occupied area to the north of the Lower Belham Valley (i.e. Old Towne north/Olveston/Salem – see Fig. 5), currently the risk exposure is MINIMAL, and the same category of risk applies to the Flemmings area where the MVO is sited. Significant changes in conditions at the volcano would be required to raise these risk levels.

28. *Risks to workers on Plymouth jetty*

There is some interest from commercial enterprises in using Plymouth Jetty to load barges with materials for export. In view of the volcanic situation, the authorities would require certain operational conditions to be met before such activities could be undertaken. The potential hazards faced by people working at, or moving to and from, the Plymouth Jetty are: sudden onset of explosive activity and associated column collapse pyroclastic flows; dome collapse pyroclastic flows; collapse of the remnant Northwest Buttress, and mudflows. There may be little or no effective early warning of an impending volcanic event which, although its probability of occurrence may be low, could have a very rapid onset, possibly affecting the Plymouth area within two minutes, or even less. It is also assumed that workers may require as much as 30 to 45 minutes to make good their escape from Plymouth and reach the Belham Valley crossing. Under these pessimistic, but by no means worst-case, circumstances, the annualised individual risk of exposure of a worker involved in such jetty operations is assessed in the LOW category on the CMO's Risk Scale. For the situation where three or more loadings per week are undertaken routinely, the individual risk exposure - whilst remaining numerically equivalent to LOW - actually lies very close to the MODERATE category. However, for all operational scenarios, the individual risk exposure estimate from volcanic activity, as it is currently assessed, is potentially higher than that of the most hazardous activity for which UK industrial and occupational accident statistics are available, which is coal-mining and quarrying of energy-producing materials. With the present volcanic hazard outlook, these levels of individual risk exposure also imply there is a non-negligible chance of losing one or more workers from dangerous volcanic activity, if such work were conducted continuously for a full year.

29. *Risks to workers in Belham Valley*

The SAC was also requested to assess the risk exposure of construction workers building foundations for the new Belham Bridge, should this project proceed. Under anticipated working circumstances, the estimated IRPA for an individual worker on this project falls into the VERY LOW category on the CMO's scale. Depending upon the exact location concerned, a similar level of volcanic risk exposure would exist for sand quarrying activities in the lower Belham Valley. It may be noted, however, that the annualised individual risk of death from volcanic hazards for such workers in the Belham Valley is estimated numerically to be higher than the exposure of construction industry workers to industrial accidents in the UK.

30. *Risk exposure for St. George's Hill*

The annualised probability of pyroclastic flow inundation affecting the St George's Hill area has been reappraised somewhat higher than previously modelled. That said, however, the threat of hazards associated with dome collapse will remain small in the St. George's Hill vicinity unless dome building to the northwest becomes re-established. Thus, volcanic hazards in this particular area are currently those from falling rock fragments from explosions, and/or pyroclastic flows from a column collapse eruption. Under the present conditions, our current estimates indicate that the risk exposure for a person living full-time on St. George's Hill falls in the LOW category on the CMO's scale, but not far removed from the threshold for MODERATE. The individual risk for individuals (e.g. tourists) making short visits to St. George's Hill is much less, but should now be regarded as falling in the MINIMAL category.

For taxi drivers who return to the area frequently, the risk exposure is more likely to fall in the LOW category (depending on the number of trips made, and time at risk). However, it must also be recognized that whilst the risk levels are insignificant for any one individual tourist, the chances of suffering two or more casualties in the period of a year, with repeated multiple visits by different groups comprising several persons, is potentially non-trivial; the actual risk exposure involved depends upon a number of contributory factors.

31. *Risks in the Maritime Exclusion Zone*

The levels of risk exposure in maritime areas and coastal waters around southern Montserrat can be viewed against the background of levels of assessed risk on land. However, the risk exposure to individual fishermen operating anywhere in the Maritime Exclusion Zone depends very much on what area they are in, and the amount of time they spend in that area (such information is not available to us for undertaking a detailed risk analysis). As before the most hazardous part of the sea around Montserrat is offshore Tar River Valley. To provide some comparative guidance, the annual individual risk exposure (IRPA) for someone *full-time* in the area directly off the Tar River delta would be classed HIGH on the CMO's scale (IRPA less than 1 in 100), while off St. Patrick's the equivalent risk category would be MODERATE. For offshore Plymouth, the *full-time* risk exposure would be assessed as LOW-to-MODERATE, while for the Trant's Bay to Spanish Point section of the east coast, the risk would fall mid-range in the category LOW. Put into numerical terms, when compared with the sea area off Tar River, the risk levels are about five times lower for fishing grounds off the south coast, sixteen times lower off Plymouth, and about thirty times lower for the seas north of Spanish Point.

The Operation of MVO

32. Our meeting was enlightening and productive, and MVO were admirable hosts, providing timely and comprehensive reports on their last six months of monitoring and participating fully in the discussions.

33. It is clear that the Observatory thrives under Dr Loughlin's directorship. The staffing at the time of the meeting was at full complement. Mr Thomas Christopher has joined MVO and is in charge of gas monitoring. It is highly gratifying now to see two Montserratians with volcanology PhDs on the staff at MVO. Another newcomer is the software engineer Machel Higgins, who replaces Mr Saranathan. Unfortunately, April will see the departure of Mr Mick Strutt, who has been a mainstay of MVO's field operations. It would be helpful to investigate

the possibility of getting some part-time technical field support from elsewhere in the region. This will leave a minimum (four) scientific staffing level. Fortunately for MVO, Dr Loughlin is to stay on for another six months until October 2006. There are three main issues with respect to future staffing at MVO. Firstly, MVO's outreach role at this time of increasing volcanic risk needs to be strengthened. Dr Loughlin has been shouldering this burden, but it would be a sound move for GoM to employ a more junior local person with a scientific background, perhaps with GIS skills and an aptitude for outreach. Secondly, the search for a "regional" candidate for the seismologist position will be tough, particularly as the Seismic Research Unit in Trinidad are searching at the same time. BGS has sufficient qualified seismology staff to see out the contract if the search draws a blank, but there will be a distinct loss of continuity if short contracts are used. Finally, and most importantly, who will succeed Dr Loughlin as Director in October 2006? Someone with volcanic crisis experience, staff management skills and close knowledge of MVO is vital, and BGS needs to act on this by June/July of this year.

34. As the dome grows there is likely to be increasing pressure on MVO to move to 24-hour working and hence provide "someone on the end of a phone" out of hours, to be capable of providing immediate information to the authorities and, if necessary, quickly initiating a call for the siren to be sounded from Salem. There is currently no direct means of MVO being alerted to the passage of a pyroclastic flow down the Belham Valley on a cloudy night. Single component seismometers and acoustic flow detectors in Tyer's Ghaut could be tested to provide such a capability.

35. Caribbean Helicopters is contracted to provide 104 hours per year of twin-engined helicopter time, and they have been operating for the last six months. This has worked quite well. In practice it has meant an average of three days worth of flying per month. At the moment the Caribbean Helicopters machine is broken, but the current contract makes it difficult to conserve underspends and use the savings later. There are also booking conflicts in the tourist high season, though the pilots will respond to an "emergency" call-out. However, the frequent tourist over-flights have meant that valuable, opportunistic dome photos have been made available to MVO. The level of flying time provision in the current contract is important to MVO's current field operations and observation needs, though a re-negotiation of the contract in September with more flexibility could improve matters.

36. Generally, the monitoring networks have performed well. The seismic network has been robust. Gas monitoring has provided a steady stream of data, though

refinements to the processing should be possible with the fixed scanning method and we encourage Mr Christopher to pursue these. Although the GPS network has worked well, the need for a programme of GPS receiver replacement was raised at the last meeting. This, together with a review of how MVO processes its GPS network data, should have a high priority in the next bid for capital funding. The new photogrammetric routine developed by Dr. Ryan based on photographs from Perche's and Galway's Mountains has yielded excellent results to meet an urgent operational need, but it is at the mercy of cloud and the helicopter. More readily accessible, lower, viewpoints may now be an option. The lack of useable operational data from the [NSF/NERC] dilatometers is a continuing disappointment. It is possible that a dedicated short-term effort at overcoming the data sensitivity/quality issues could yield dividends here, but it would require an experienced person with external funding. MVO has been well-served by Dr Devine's petrological monitoring in the past, but his current priorities towards work at Mt. St. Helens leads us to recommend that MVO consider acquiring its own basic petrological microscopy and thin section making capability, together with exploring alternatives for a faster turn-around expert service.

37. Collaboration with numerous research groups continues to provide stimulation and new data to MVO staff. Two visits with the AVTIS instrument have shown the operational potential for this new mm-wave radar technology to monitor dome growth. A microgravity survey by a Bristol University student may provide complementary deformation data to the GPS. Reconnaissance resistivity surveys by workers from Rennes University and geoelectric surveys by BGS are planned. Any commercially-driven geothermal development should feed data to MVO. An upward-looking ash radar is to be tested at Gerald's airport in collaboration with USGS.

38. The current management contract for MVO held by BGS expires in March 2008. To prepare for the contract renewal process, the MVO Board would like a Scientific and Management Audit (SMA) of MVO to be undertaken and have asked the SAC to suggest suitable terms of reference for such an audit, together with suggestions as to who might undertake it. Our suggested terms of reference comprise Appendix 6.

39. We consider that an appropriate membership of the MVO SMA team would be:

(i) A senior international volcanologist with experience of observatory management elsewhere.

(ii) A senior volcanologist with experience of Montserrat.

(iii) A manager from a company with a scientific and technical background, or, a senior regional civil servant (or former civil servant) with extensive experience of government-funded official agencies and capacity-building.
(iv) A specialist in IT/communications.

The process of audit should include a short (2-day) site visit for briefings and interviews. Soundings indicate that it is unlikely that organisations such as USGS or professional risk assessment companies would be willing to run such an exercise. There is one regional consultancy group – The Caribbean Consulting Group – who have the capabilities to undertake an SMA of this kind (Dr Aspinall is associated with The CCG, and would be able to provide good guidance). Alternatively, the SAC membership could attempt to recruit the SMA team, though administrative support for the reporting process would need to be found elsewhere.

SAC Membership

40. Professor Cashman joined the SAC at this meeting. Her experience at Mt. St Helens will be of value in better understanding Soufrière Hills Volcano. We do not expect any immediate future changes in membership.

Next SAC Meeting

41. The rapidity of change in the state of activity of the volcano over the last six months leads us to recommend that a new hazard and risk assessment be undertaken in six months time, in September 2006.

Appendix 1: Constitution of the Scientific Advisory Committee on Montserrat Volcanic Activity

This document outlines the main responsibilities of the Scientific Advisory Committee (SAC) on the Soufriere Hills Volcano, Montserrat. The document includes the terms of reference for the SAC and a membership template. The SAC is to replace the Risk Assessment Panel and is commissioned by the Overseas Territories Department (OTD) of the Foreign and Commonwealth Office (FCO). The SAC will work according to the Office of Science and Technology (OST) Code of Practice for Scientific Advisory Committees.

TERMS OF REFERENCE
The main responsibilities of the SAC are:

1. to carry out regular hazard and risk assessments of the volcano in co-operation with the Montserrat Volcano Observatory (MVO) and to report its findings to HMG and the Government of Montserrat; and

2. to provide scientific advice at a strategic level to HMG and the Government of Montserrat outside these regular assessments in co-operation with the MVO.

NB: The “Government of Montserrat” will normally mean, in the first instance, the Governor as s/he has the constitutional responsibility for the safety of the Montserrat population. The Governor will be responsible for ensuring appropriate dissemination of SAC assessments or recommendations to the Government and people of Montserrat.

The SAC is also required to perform these additional functions:

3. to provide independent advice on the scientific and technical operations of the MVO to ensure that the work matches the level of risk;

4. to provide scientific advice and assistance to the MVO as required by the MVO Director; and

5. to offer advice on new developments that were not foreseen when the TORs were set up, and if appropriate make recommendations for changes to the TORs.

The SAC will carry out its activities within the OST Code of Practice for Scientific Advisory Committees. The SAC will be responsible to the UK Government through the FCO (OTD). The SAC will not incur expenditure without prior FCO (OTD) authority.

These general terms of reference are supplemented with the following specific points:

(a) The work of the SAC concerns scientific assessment of the volcanic activity and related hazards and risks. This scientific work is an input to decisions made by the HMG and the Government of Montserrat related to the safety of the people of Montserrat (such as evacuation and extent of Exclusion Zones), to issues of planning and sustainable development of Montserrat and to the mitigation of external hazards (e.g. to civil aviation).

(b) The provision of scientific advice to the Governor and Government of Montserrat is the responsibility of the MVO and its Director. The SAC has the function of assisting the MVO in its major missions in all respects of its activities and to assist in matters relating to the provision of long-term and strategic matters.

(c) The MVO Director (or scientific staff designated by the Director) participate in all SAC activities except for ToRs 3 and 4.

(d) The SAC has the function of giving advice and assistance to MVO and the management contractor relating to scientific matters as required by the MVO Director. Such independent advice to the MVO may include appraisal of the technical expertise of staff, evaluation of the monitoring systems, assessment of proposed research projects by external groups, and advice on technical matters.

(e) With respect to ToR 3 the Chair of the SAC will be a member of the MVO Board of Directors and can provide independent advice to the Board as required. The Chair will be expected to attend MVO Board meetings (currently twice a year).

(f) Given the special circumstances of Montserrat as a United Kingdom Overseas Territory, reports of the SAC would be provided for both Governments. Reports would also be given to the MVO Management Board.

(g) The SAC will be required to present its findings in a manner suitable for release to the public. It will also be required to assist the Governments and the MVO in explaining the activity of the volcano and the scientific information pertinent to decision-making by the authorities.

(h) The SAC will liaise with other relevant scientific organisations or committees as required, which might for example include regional scientific institutions and the Department of Health Committee on health hazards from volcanic ash.

(g) The Chair of the SAC will make an annual report to the MVO Board of Directors.

MEMBERSHIP

Membership of the SAC will be at the invitation of the FCO (OTD) and will cover the key areas of expertise required to assess the hazards and risks of erupting volcanoes. Expertise will include such areas as volcanology, volcano geophysics, and hazard analysis. The SAC will continue the approach of the former Risk Assessment Panel that was endorsed by the UK Chief Government Scientist in December 1997. Thus the Committee requires a facilitator as a member for applying expert elicitation methods to estimate volcanic risk. These considerations imply a minimum of four members, excluding the Director of the MVO. Additional experts can be invited to participate as required by the Chair, with prior agreement from the FCO (OTD), if a lack of expertise becomes apparent on a particular issue. As required by the Code the SAC is expected to consider external opinion. The membership will be considered on an annual basis with a view to regular changes and refreshment of membership.

MEMBERSHIP TEMPLATE

Members invited to serve on the SAC for the Montserrat Volcano are expected to attend all hazards and risk assessment meetings and to participate in the formalised elicitation procedure. Members have the responsibility to use their scientific judgement and expertise to meet the Terms of Reference. Opinions of the Members on scientific matters should be expressed through participation in the work of the SAC. Divergences of scientific opinion will normally be reported in terms of scientific uncertainty through the formal expert elicitation procedure. Differences that cannot be incorporated through the elicitation methodology should be included in the reports of the SAC as required by the OST Code. The Chair of the SAC, or his or her delegate from the Committee, will be responsible for presenting the findings of the SAC's work to the Governments of Montserrat and the United Kingdom and to the public in co-operation with the Director of the MVO. Any disagreement or divergence of opinion with the Director of the MVO that cannot be reconciled or incorporated through the elicitation method should be reported through the MVO Board of Directors.

SECRETARIAT

The FCO (OTD) will provide a Secretariat for the SAC, as set out in the Code of Practice. FCO (OTD) will reimburse premium economy travel costs, reasonable hotel accommodation, meals and professional fees (once agreed) in full. The SAC will not incur additional expenditure without prior FCO (OTD) authority. The Secretariat's main point of contact is Ann Birch, Desk Officer for Montserrat in OTD. Her contact details are as follows:

Email: ann.birch@fco.gov.uk
Tel: +44 20 7008 3123
Fax: +44 20 7008 2879

Appendix 2: Scientific Advisory Committee on Montserrat Volcanic Activity, Meeting 6 , 27 – 29 March, 2006 : Agenda

1. SAC5 report, interim report, plan for this meeting, public meeting
2. MVO Activity Report
   Petrology *(Devine report)*
3. Dome growth scenarios *(Wadge/Voight presentations)*
   Dome collapse pyroclastic flows
   Crater wall collapse
4. State of the volcanic system, petrologic evidence *(Cashman presentation)*
5. Long-term prognosis
   1-5 years
   5-20 years
6. One year hazard scenarios elicitation
7. Risks in the Lower Belham
8. Risks in the former DTEZ
9. Work/Visit
   a. St. George's Hill
   b. Plymouth workers
   c. Plymouth tourists
   d. Belham bridge/sand
10. Maritime exclusion zone
11. MVO Matters
    a. Staffing
    b. Helicopter
    c. Monitoring
    d. Collaboration
    e. Science and Management Audit
       Terms of Reference
       Organisations that could undertake audit
12. SAC Matters
    a. Membership
    b. Next meeting

Appendix 3: List of Participants

Chairman

Prof. G. Wadge	Environmental Systems Science Centre, University of Reading, UK

Committee members

Dr. W.P. Aspinall	Aspinall & Associates, UK
Prof. K.V.Cashman	University of Oregon, USA
Prof. J. Neuberg	Leeds University, UK
Dr. R.E.Robertson	Seismic Research Unit, The University of the West Indies, Trinidad and Tobago
Prof. B. Voight	Penn. State University, USA

MVO Scientists present in an advisory capacity:

Dr. S. Loughlin (Director, MVO)

Dr. V. Hards

Dr. R. Luckett

Dr. G. Ryan

Mr. M. Strutt

Mr. T. Chrisopher

Mr. T. Sayers (part of the time)

Appendix 4: SAC6 Preliminary Statement issued 29 March 2006

The third episode of lava dome growth is now eight months old. The dome has grown within the crater to a height of about 250 metres above its base, an altitude of 930 metres above sea level, and its margins have reached to just below the crater rim on the northwest, but not to the south. Thus far there have been no major collapses or explosions.

Lava was extruded at a rate of one cubic metre per second or less for the first three months of the current episode, but that rate increased in late November to about three cubic metres per second. In the second week of February the rate increased to over ten cubic metres per second for a period of about two weeks, forming a large lobe of lava on the northern side of the dome above Farrell's. Since then the extrusion rate has fallen to about two cubic metres per second in late March with growth currently on the eastern side facing Tar River Valley. The average rate over this current episode is about three cubic metres per second, a rate comparable to the average rate of the first (1995-8) episode of dome growth.

The dome must grow much larger to approach the size of that of late 2002 to 2003. A large collapse down the Tar River Valley, which is the most likely collapse event, would lengthen the period to achieve such a large value. The potential for collapse of the dome lava to the west or north, leading to the possible generation of pyroclastic flows in the Gage's valley and Tyer's Ghauts, has increased. Also, the likelihood of a collapse of the Northwest Buttress remnant into Gage's valley that would produce a rock avalanche towards Plymouth has increased. Rapid growth of lava lobes on the northwestern sector of the dome could trigger such collapses.

The overall level of risk to people as a result of this quite vigorous resumption of dome growth has increased from six months ago. In particular, the risk of flows reaching Plymouth, St. George's Hill and the Belham Valley at least as far as Cork Hill has increased over the next year.

A full report of the hazards and detailed risk assessment for a year ahead will follow

Appendix 5: SAC Interim Statement on SHV activity 17 February 2006

Background

The rate of growth of the new lava dome increased during the last ten days. In response to concerns about the changed levels of risk, particularly to those working in Plymouth, members of the SAC (Wadge, Aspinall) with MVO advice have re-assessed them for the period of the next two months. A full SAC hazard and risk assessment will take place from 27 to 29 March 2006.

Current and Future Growth of the Lava Dome

The main relevant facts are as follows:

1. Since the current episode began in August 2005, the rate of growth of the dome has increased from less than 1 cubic metres per second to about 3 cubic metres per second. In particular, there is evidence that in January 2006 and in the second week of February 2006, the rate rose to greater than 5 cubic metres per second, though only for limited periods.
2. Currently the dome nearly abuts the crater rim on the parts of the north and northwestern crater rims after the recent spurt of growth. Although no material has overtopped the crater rims, minor rockfalls down Gage's and Farrell's Walls will soon be possible. However, there is no great height of dome material capable of collapsing and producing pyroclastic flows down the west and northwest flanks as yet. The old dome remnant that stands above Gage's valley has a volume of approximately 2 million cubic metres, which if pushed outwards could generate an avalanche that could travel 3-4 km into the upper parts of Plymouth.
3. The activity of 9-10 February was loud and vigorous and probably involved phreatic (groundwater) interaction with the magma, rather than solely magmatic gas depressurisation. So far there have been no signs of explosive depressurisation of the dome lava or magma in the conduit. This may be because this magma is less volatile-rich than in 1997, or magma fluxes have yet to rise to the rates that might trigger explosive decompression.
4. The dome is still far from the Galway's wall, the only part of the crater wall that has collapsed during the eruption (26 Dec. 1997). The Gage's and Farrell's Walls must have withstood much higher dome loading stresses during 2002-3 without failing. Thus there is no past precedent, nor new evidence for the likely outward failure of these parts of the volcano to produce debris avalanches and pyroclastic flows that could threaten Plymouth, but the potential exists.

5. Forward growth modelling suggests that it will be many months before the dome is capable of growing to a sufficient height and mass to be capable of collapsing and generating pyroclastic flows in any other direction other than Tar River Valley.

Hazards

Our current assessment is that the current dome poses the same types of hazard as previously evaluated and foreseen in the SAC reports:

1. Dome collapse pyroclastic flows. This is most likely to be confined to the Tar River Valley. A large collapse (greater than 10 million cubic metres) could depressurise magma in the conduit leading to explosions. Moderate collapses (greater than 1 million cubic metres) to the west and north are unlikely in the next two months.
2. Explosive column collapse generating ash and pyroclastic flows could result from (1). The threat from column collapse pyroclastc flows is increased because the northwestern walls currently offer no protection.
3. Structural failure of the Northwest Buttress remnant leading to debris flow and pyroclastic flow down Gage’s valley, possibly as far as upper Plymouth.

Risks

Plymouth

The individual risk to jetty-based workers in Plymouth assessed in September 2005, was LOW on the CMO's Risk Scale. For these and similar workers currently assessed to be working in Plymouth the risk has increased to the point at which it should be considered MODERATE. Collectively, there is approximately a 1% chance of suffering two or more fatalities amongst thirty such workers so engaged.

The individual risks for individuals (e.g. tourists) paying short visits is much less, but should now be regarded as falling in the MINIMAL category. However, it must also be recognized that whereas the risk levels involved are insignificant **for any one individual tourist**, the chances of suffering two or more casualties in a given period involving repeated multiple visits by different groups comprising several persons is potentially non-trivial, and this risk depends upon a number of factors. For taxi drivers, the risk exposure moves up to LOW category, from VERY LOW.

The time from the start of the collapse/explosion event to the arrival of any flows into Plymouth may be as little as ninety seconds.

Belham Valley

The immediate risks to people living in the lower Belham Valley (Isles Bay, Cork Hill, Old Towne) is raised by the possibility of an explosion generated column collapse flow entering the upper part of the Belham catchment. Although the risk to lower Belham has increased it is still in the LOW category.

17 February 2006

Appendix 6: Draft Terms of Reference for a Scientific and Management Audit of MVO

The aim of the audit is to evaluate the fitness of the Montserrat Volcano Observatory in pursuing its goal of providing advice to the Governments of Montserrat and the UK on the volcanic activity at Soufrière Hills Volcano in terms of the following:

1. Practice of the most appropriate instrumental methods of monitoring the volcano and the best scientific analysis of available data.
2. The timely and judicious presentation of scientific advice to government.
3. That the qualifications and calibre of the staff, their number, management and level of available resources are fit for purpose.
4. The necessary links to, and opportunities for collaborations with, the appropriate organisations in government, the wider scientific sphere and with the public of Montserrat are in place.
5. How the future operation of the MVO might change and improve, including the identification of opportunities and threats.

Appendix 7: Glossary of Terms

Andesite: The name given to the type of magma erupted in Montserrat.

Basalt: The type of magma entering the magma reservoir below Montserrat.

cGPS: Continuously-measured Global Positioning System for repeated measurement of ground deformation.

Conduit: In a volcano magma flows to the earth's surface along a pathway known as a conduit. The conduit is usually thought to be a cylindrical tube or a long fracture.

EDM: Electronic Distance Measurements made by laser ranging to reflectors gives length changes of a few millimetres accuracy over several kilometres.

Hybrid/LP Seismicity: Varieties of earthquake signal often indicative of magma motion in the upper part of the conduit.

Lava: Once magma gets to earth’s surface and extrudes it can be called lava. Below ground it is always called magma.

Magma: The material that erupts in a volcano is known as magma. It is not simply a liquid, but a mixture of liquid, crystals and volcanic gases. Magma must contain enough liquid to be able to flow.

Magnitude: The magnitude of an explosive eruption is the total mass of material erupted.

Mudflow: A flow of rock debris, ash and mud that occurs on many volcanoes particularly during eruptions and after very heavy rain

Pyroclastic flow: These are flows of volcanic fragments similar to avalanches of rock in landslides and snow avalanches. They can be formed both by explosions and by parts of an unstable lava dome avalanching.

Pyroclastic surge: These are also flows, but they are dilute clouds rather than dense avalanches. A surge is a rapidly moving mixture of hot particles and hot gas and their behaviour can be compared to a very severe hurricane. Surges can be formed above pyroclastic flows or directly by very violent explosions.

Swarm: A large number of , in this case, earthquakes occurring in rapid succession with characteristics indicating they are generated from a similar region in the earth. Can merge into tremor.

Volcanic ash: Ash particles are defined as less than 4 millimetres in diameter. Respirable ash consists of particles less than 10 microns (a micron is one thousandth of a millimetre) in diameter.

Appendix 8: Chief Medical Officer's Risk Scale

Negligible*:* an adverse event occurring at a frequency below one per million. This would be of little concern for ordinary living if the issue was an environmental one, or the consequence of a health care intervention. It should be noted, however, that this does not mean that the event is not important – it almost certainly will be to the individual – nor that it is not possible to reduce the risk even further. Other words which can be used in this context are 'remote' or 'insignificant'. If the word 'safe' is to be used it must be seen to mean negligible, but should not import no, or zero, risk.

Minimal*:* a risk of an adverse event occurring in the range of between one in a million and one in 100,000, and that the conduct of normal life is not generally affected as long as reasonable precautions are taken. The possibility of a risk is thus clearly noted and could be described as 'acceptable' or 'very small'. But what is acceptable to one individual may not be to another.

Very low*:* a risk of between one in 100,000 and one in 10,000, and thus begins to describe an event, or a consequence of a health care procedure, occurring more frequently.

Low*:* a risk of between one in 10,000 and one in 1,000. Once again this would fit into many clinical procedures and environmental hazards. Other words which might be used include 'reasonable', 'tolerable' and 'small'. Many risks fall into this very broad category.

Moderate*:* a risk of between one in 1,000 and one in 100. It would cover a wide range of procedures, treatment and environmental events.

High*:* fairly regular events that would occur at a rate greater than one in 100. They may also be described as 'frequent', 'significant' or 'serious'. It may be appropriate further to subdivide this category.

Unknown*:* when the level of risk is unknown or unquantifiable. This is not uncommon in the early stages of an environmental concern or the beginning of a newly recognised disease process (such as the beginning of the HIV epidemic).

Reference: On the State of Public Health: the Annual Report of the Chief Medical Officer of the Department of Health for the Year 1995. London: HMSO, 1996.