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

Fifth Report of the Scientific Advisory Committee on Montserrat Volcanic Activity

Based on a meeting held between 26 and 28 September 2005 at the Montserrat Volcano Observatory, Montserrat

Part I: Main Report

Issued 21 October 2005

Summary

(i) A new lava dome began to grow during the first week of August 2005, the third such episode during the eruption. An increase in surface activity began in April 2005, which was mainly phreatic with increased water vapour and ash emission from vents. Surface activity declined in May, but seismicity and deformation increased abruptly in early June, just before a new fracture formed in the crater. In June, the first indications of the presence of new magma in the erupted ash were detected. From 28 June to 27 July a series of five explosions effectively cleared the way through the old conduit for magma to rise to form the new lava dome. The dome has grown steadily with a shape elongated to the northwest behind the transverse remnant of old dome material in the crater.

(ii) The measured rate of growth of the dome gave an extrusion rate of lava of about 0.5 - 1 cubic metres per second during the first two months. In the April 2005 SAC meeting we had considered such a "slow" re-start more likely than a "fast-growth" re-start. This is significant from a hazard perspective because the likelihood of explosive activity is reduced in the short term, and because the time it will take to build a dome big enough to overtop the crater walls and produce dome collapse pyroclastic flows outside the walls, is considerable, about two to three years. The extrusion rate in October 2005, calculated since the SAC meeting in September, appears to be increasing from this initial low value. If this is confirmed and the rate sustained then the hazards will increase. We will monitor this carefully with MVO and if we judge the hazards to have increased significantly from the analysis presented here then we will re-analyse the situation and report again in the coming weeks.

(iii) Despite the resumption of dome growth, the overall level of risk that the volcano poses to Montserrat is only marginally greater than it was. This is because the certainty of new lava extrusion is balanced by the reduced extrusion rate that we now see. The risks posed to individuals in the former Daytime Entry Zone (DTEZ) and visitors to Plymouth are similarly little changed for the time being, but are likely to rise as the dome grows.

(iv) We have considered the issue of exposure to sulphur dioxide and hydrogen chloride from the volcano's gas plume, particularly in and around the former DTEZ. Recent measurements at ground level in these areas have shown high concentrations on occasions that should warrant warnings to those persons with asthma or other sensitive conditions who may consider spending time there.

Contents

Introduction

1. The fifth meeting of the Scientific Advisory Committee (SAC) on Montserrat Volcanic Activity took place at the Montserrat Volcano Observatory (MVO) from 26 to 28 September 2005. 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: Prof. G. Wadge (SAC Chairman), Dr. W.P. Aspinall (SAC), Dr. S. Loughlin (MVO, SAC), Dr. R. Luckett (MVO), Prof. J. Neuberg (SAC), Dr. R. Robertson (SAC), Dr. G. Ryan (MVO), Mr. M. Strutt (MVO), Prof. B. Voight (SAC). Miss V. Bass (MVO) and Mr T. Syers (MVO) were present for part of the first day. Appendix 3 gives a list of participants and their affiliations. An apology for absence was received from Professor K. Cashman (SAC).

3. Shortly after the last SAC meeting (4-6 April, 2005) the volcano began an episode of increased seismicity and increased gas and ash production. After several intervening periods of activity, which included some explosions, a new lava dome began to be extruded in the first week of August. This report is largely concerned with this resumption of dome growth and its implications for volcanic risk. We have also studied the hazards that could be posed by the gas plume and by extreme explosive behaviour.

4. During the *"Ten Years On"* Scientific Conference held in Montserrat from 24 to 29 July, members of the SAC who were present convened briefly on two occasions to consider the changing situation and report to government. Notes from those meetings are presented in Appendix 5.

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 6 has a glossary of technical terms. A Preliminary Statement (Appendix 4) was issued on 28 September. An interview involving Wadge and Loughlin that discussed some of the preliminary findings of the risk assessment meeting was broadcast on ZJB Radio that same day. Also on that day the SAC and MVO held a public meeting at Brades, chaired by Sir Howard Fergus and also recorded by ZJB, to explain the preliminary findings to the public.

Recent Volcanic Activity

6. On 14 April 2005, a week after the last meeting, the strongest surface activity since the 3 March 2004 episode began. Vigorous gas and ash release from a vent on the northwest part of the crater was accompanied by jet roaring noises. There were also small active vents just outside of the crater wall. On 13 June, after a storm, a new, NNE-trending line of vents appeared in the crater accompanied by

elevated seismicity. Two weeks of ash and gas venting followed. On 28 June, the first of a series of five explosions occurred, the others being on 3, 9, 18 and 27 July. They were typically preceded or followed by hybrid earthquakes, produced ash columns up to ten kilometres above sea level and sent column collapse pyroclastic flows down the Tar River valley to the sea. In the case of the 28 June explosion, and the only one in daylight hours, minor pyroclastic flows were seen to descend Tyer's Ghaut for a few hundred metres. These explosions sent some ash over the western side of the island and each explosion involved dense rock equivalent volumes of about three hundred thousand cubic metres. The location of the vent for the last explosion was that of the main vent of the eruption and the new dome.

7. During the April to July 2005 period it became clear that the surface activity was located along a set of fractures cutting across the crater and crater walls. These fractures are: (i) a NW-trending fracture running from the 14 April vent through the central vent to the southeast, (ii) a NNE-trending fracture formed on 13 June that crosses the transverse ridge of old dome rock inside the crater, from near the central vent, (iii) a tangential ENE-trending fracture that may represent the surface trace of the old northern crater rim, and (iv) another ENE-trending fracture that bounds an area of uplift on the southern side of the crater first seen during initial dome extrusion. These fractures were formed, or re-activated, in response to rising magma during mid-2005.

8. The new lava dome was recognised from a helicopter on 8 August following a period of cloudy weather. In order to have reached the size at which it was observed, we infer that it began to form during the first week of August. It grew over the next few weeks from the site of the main feeder conduit that produced the "domelet" during the last week of July 2003. Its shape and blocky surface character changed during these two months. A massive, vertically-fractured slab formed in mid-August and was pushed eastward. At times the dome appears to have grown by swelling internally. By the end of August a shallow depression had formed on the dome and over the vent, and the growth was mainly to the west. By then it was consistently elongated to the WNW. On 24 August it was about 195 metres long, 150 metres wide and 80 metres high, and abutted the main transverse ridge of old dome rock on the northeast. Estimates of its changing volume and hence its rate of growth during August and September indicate an extrusion rate of between 0.5 and 1 cubic metres per second. This is a key observation. It places it in the lowest class of rate of extrusion that we considered in previous re-start scenarios (less than two cubic metres per second).

Monitoring Data

9. The overall level of seismicity during the last six months was raised relative to the previous six months, but still at a very much lower level than preceded either of the previous episodes of dome growth in 1995 and 1999. Volcano-tectonic earthquakes became more frequent following the 14 April event, but the most significant change in seismicity occurred on 6 June. Hybrid, long-period and rockfall seismicity all increased, though no further increase occurred that could be associated with the appearance of the dome itself. Since early September a series

of small, very similar volcano-tectonic earthquakes have been recorded. Interesting though these patterns are, they were not interpreted unequivocally at the time as corresponding to imminent rise and extrusion of lava. An analysis of the stress fields at the time of the volcano-tectonic earthquakes suggests a major change in stress orientation in late May 2005.

10. Surface deformation measured by GPS showed a varied response to the resumption of lava extrusion. The four most northerly instruments showed changes in motion beginning in April 2005, at the time of the renewed surface activity. The two most southerly instruments did not. The vertical components of motion indicate a deflationary event began in April and a reversal of this in mid-June. The Hermitage instrument moved sharply southwest, towards the crater, from April. This reinforced some previous thinking that the motion of this instrument may be largely controlled by a local source, perhaps aseismic slip on a nearby fault. New EDM measurements to the Hermitage site have been initiated to provide further insights on this question. A wider programme of EDM work has begun to monitor the possible motions of the outer crater walls, giving baseline data should the growing dome press against them at some future time.

11. Smoothed sulphur dioxide atmospheric emission rates have generally risen from lower-than-average rates of about 300 tonnes per day in April to about 800 tonnes per day in August. During the 2003-2005 pause in extrusion, the ratio of hydrogen chloride to sulphur dioxide was in the range 0.3 - 0.4. Since early June 2005 the ratio has climbed to about 0.8, evidence suggesting degassing of hydrogen chloride from andesite magma at shallow depths (less than two kilometres). Though this is still less than the ratios of greater than 1 seen in the last extrusive episode, we do expect it to climb if the extrusion rate increases.

12. Diffusion tube measurements of sulphur dioxide accumulation at ground level over one month (recently changed to two weeks) showed some very high levels of gas concentration at Plymouth and Richmond Hill during June and July. This is discussed in more detail in the section on gas hazards.

13. Prior to the previous resumption of extrusion in November 1999 there had been a series of explosions over three weeks producing pumice generated from fresh magma. Hence a close study of the petrology of ash samples taken since April 2005, including the explosions of June and July 2005 was made to search for similar evidence of this kind. No such obvious signal was detected. Instead a more subtle change in the nature of the explosion products was found. The early ash deposits were interpreted as entirely old conduit fill with abundant hydrothermal mineralisation. In June, small fragments of glass appeared in increasing abundance, indicating some new magma was then present. Ash erupted after the dome appeared showed fresh amphibole crystals for the first time, indicating magma had risen to the surface relatively quickly. The dome itself has not yet been sampled.

Probable Future Behaviour

14. In the last report at the beginning of April 2005, we concluded that the eruption was not yet over, that on the evidence available at the time the likelihood of dome growth in the following twelve months was about one in four, and that if it did resume it would most likely be at an extrusion rate of less than 2 cubic metres per second. This was borne out, except that in reality dome growth started within four months. However, the enhanced possibility of a re-start based on the new activity was noted in the SAC mini-meetings held in July 2005, with this opinion conveyed to the Governor and Chief Minister. The indications are that the process of the unblocking of the conduit and the rise of magma from the reservoir began in April, accelerated in early June and was complete at the beginning of August.

15. This then represents the likely start of a possible third major episode of lava extrusion during the eruption; the other two being 1995-1998 and 1999-2003. Will the volcano effectively repeat one of these episodes or will it follow a different path? The first two episodes were very different from one another. The 1995-1998 extrusion rate started from very low values and gradually accelerated into late 1997, whilst the 1999-2000 rate was much more even. The average extrusion rates of the two episodes over 2.5 and 3.5 years respectively were about 3 and 2 cubic metres per second. This current episode has begun with a low extrusion rate (less than one cubic metres per second), more suggestive of 1995. This rate could rise to match either of the other two episodes. The most recent visual observations suggest that this may be happening, but a set of more precise measurements are needed to confirm whether this is so, or not.

16. The ten year long eruption of Soufrière Hills Volcano 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 is about 77% and for another twenty years is about 43%.

Assessment of Volcanic Hazards

17. The resumption of lava extrusion means that many of the hazards that have been experienced in previous episodes of dome growth: explosions, column collapse pyroclastic flows and dome collapse pyroclastic flows, could occur again in the next few years. However, the relatively low average rate of lava extrusion seen so far suggests that the severity and rapidity with which these may recur is less than would have been the case with a more vigorous re-start. The following assessment of hazards and risks is based on this view of the average rate of extrusion during the first two months of the new dome growth. This was the situation at the time of SAC assessment. If there is confirmation from new data that the extrusion rate has increased and it becomes apparent that the volcanic hazards have changed substantially from that presented here, then we will re-analyse the situation formally again within a period of weeks.

18. The focus of our attention was once again the former DTEZ and other areas within the Exclusion Zone where economically important undertakings might be considered, such as tourist facilities and industrial enterprises.

19. Hazards from falling rocks and ash from explosions and from pyroclastic flows from collapsing ash columns (as seen on 28 June 2005) are the main concern over the next year, though it is probable that these will be less severe than experienced during the explosions of the June-August 2005 re-start period. We judge that it may be 2-3 years before the dome grows sufficiently to pose a threat from dome-collapse pyroclastic flows to the west and north as in 2002-3. This, however, is largely dependent on the rate of lava extrusion. Future higher rates would advance the onset of this potential hazard. It is also possible that the extrusion may stop.

20. On the rim of the crater left by the collapse of July 2003 are remnants of old dome rocks, including the "Northwest Buttress". The phreatic activity of April-July 2005 involved the opening of vents near their bases and it is possible that this has made them more liable to collapse, producing a cold debris avalanche. However, their relatively small size and propensity to fall into the crater rather than outside it means that they pose very little threat to populated/visited areas of the former DTEZ. If and when the new dome grows big enough to press against them then we will re-evaluate this situation.

21. Mudflow hazard related to storm rains in the lower Belham Valley continues at the same level as previously reported. Re-vegetation of the upper catchments that feed the mudflows would reduce their occurrence. The new dome growth probably sets back this process. The mudflow deposits will continue to raise the river bed at the crossing area as we indicated in an earlier report. Over the next year the likelihood of pyroclastic flows reaching the lower Belham Valley is very low.

22. We considered the hazard posed by gas from the volcano to people living or visiting the former DTEZ and Plymouth. The winds carrying the gas plume mean that the sector from Kinsale to Old Road Bay (i.e. former DTEZ/Plymouth) receives most. During June - July 2005 concentrations of sulphur dioxide at ground level exceeded World Health Organization (WHO) air quality thresholds in these areas. Sulphur dioxide and to a lesser extent hydrogen chloride are the main hazardous gases. These gases can be unpleasant to the average person, but particularly at risk are those with asthma. Warnings to asthmatics entering these zones are warranted, particularly for those without inhalers.

23. We also considered at this meeting the likelihood of future explosions of a much greater magnitude than we have seen before in this eruption. Such explosions (e.g. 10x reference intensity) could produce ash thicknesses of many tens of centimetres to a metre over much of the island and would tap into the magma reservoir to do so. The evidence on land and from the recent borings through sea-bed deposits around Montserrat indicates that such deposits are very rare and that the likelihood of them occurring in the future is very low.

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. Overall the risk to the people of Montserrat from volcanic activity over the next year is similar to that estimated six months ago. The growth of the new dome increases the level of hazard but this is largely offset because the rate of lava extrusion is relatively low so far. Had the initial extrusion rate been significantly higher then the risks would have been much greater. Our downward re-assessment of the likelihood of very large explosions (i.e. much larger than anything seen so far) also means that the estimated risk levels from such extreme events are very low.

26. Assuming the dome continues to grow then we anticipate that the risk levels in succeeding assessments will start to rise again as the possibility of dome collapse pyroclastic flows to the north increases. This will require growth over several years unless the extrusion rate increases to much higher sustained levels.

27. *Risks in the former DTEZ*
Given that dome growth has only just re-started, and is proceeding at a low extrusion rate, the most immediate hazards to people residing or working in the former DTEZ 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 the former DTEZ, and can be mapped from the simulation models. The hazards from column collapse pyroclastic flows would be concentrated in areas adjacent to Gage's Valley, and, marginally, in the Belham Valley between the volcano and Cork Hill. With current conditions, the individual risk exposure for the former DTEZ is assessed LOW on the CMO's scale. However, the risk could move into the MODERATE or even HIGH categories for some areas of the former DTEZ if there is a switch to much higher rates of extrusion rate.

28. *Risk exposure for St. George's Hill*
Under the present conditions, our current hazards model indicates that the risk exposure for a person living full-time on St. George's Hill is LOW on the CMO's scale.

29. *Risks to workers on Plymouth jetty*
The risk to workers at the Plymouth jetty in the present conditions is assessed based on 10 workers working on the jetty eight hours per day, five days a week.

The annualised individual risk of exposure of a worker on the jetty continues to be assessed in the LOW category on the CMO's Risk Scale.

30. *Risks to tourists and short-term visitors in Plymouth*
For a tourist or person who makes a single short visit to an area with elevated risk (say, a trip into the middle of Plymouth of about two hours in duration), their limited time of exposure would correspond to an annualised individual risk of death or injury in the category NEGLIGIBLE on the CMO's Scale. For taxi drivers or others who make regular short-term visits week-on-week, although the chances of becoming a casualty would be higher, the individual risk can be expected to fall still in one of the categories MINIMAL, VERY LOW or LOW, depending on all the circumstances involved. A higher risk would be involved for persons with a medical condition such as asthma at times of high gas concentration, as previously mentioned.

31. *Risks to people working in the daytime at Trant's Quarry*
The risks to individual workers present in this area during normal working hours are judged to be equivalent to VERY LOW.

32. *Risks in the Maritime Exclusion Zone*
We note that the Maritime Exclusion Zone has not been changed by the Government since our last analysis, in which the hazard levels in some of the coastal areas were reduced. Without detailed information on how long individual sailors (fishermen) spend in the Zone we can only provide a comparative estimate of risk. The sea area off Tar River is easily the most hazardous, as before. For a fisherman in his boat full-time off the Tar River valley the individual risk exposure would be classed as HIGH on the CMO's scale. However, areas off the Whites River on the south coast, Plymouth and Spanish Point are five, sixteen and thirty times less hazardous respectively.

The Operation of MVO

33. We enjoyed our meeting greatly and benefited from a very comprehensive MVO report on the recent activity and monitoring efforts. Two of us were able to experience the new helicopter service for MVO in visits to field sites. The Observatory should be well served by this new arrangement.

34. It was clear that the Observatory was working well with morale at a high level under Dr Loughlin's leadership. By the end of the year the deformation monitoring post (currently Mr. Strutt) is due to be filled by a "regional" scientist. Mr. Saranathan, the software engineer, has been offered a contract renewed for another year. The scientific technicians, Mr. Syers and Miss Bass are becoming increasingly involved in scientific decisions. Unfortunately, they are both at the top of their salary scale although their responsibilities are increasing; this issue will be addressed at the Operations Board. Dr Loughlin is due to step down as Director next April and her replacement is not yet confirmed.

35. The new one-year contract with Caribbean Helicopters for MVO support using a twin-engined machine began whilst we were meeting. It allows for 104 hours

flying time from MVO per year to be called as required in two-hour blocks. It appears that this amount of flight time may be sufficient, but we suspend judgement until we can observe the experience of operations against the real needs of MVO. Two impediments to the optimum utilisation of this provision are the lack of a fuel dump at MVO and the current necessity for the helicopter to report at both the Antigua immigration authorities and to Montserrat immigration prior to arrival at the MVO heli-pad. We encourage the resolution of these two problems.

36. Dome survey is currently a priority. The establishment of automated cameras at Perches on 20 September and at Galway's ridge in the near future will enable photogrammetry to be undertaken. The laser imaging survey from Perches by Mr Jones on 16 August gave good results. An equivalent airborne lidar survey could yield valuable whole-crater survey information, but would be prone to cloud/steam obscuration and delay. Any purchase of a set of laser ranging binoculars with goniometric pointing control should be preceded by a field trial. An experiment with the AVTIS radarometer from Perches is planned that will be free from the limitations of cloud. The seismic network has had some modification to its repeater stations and is working well. We encourage the use of fault plane solution-based stress field analysis from volcano-tectonic earthquakes as an "operational" procedure at MVO. MVO currently owns only two of the operational GPS receivers, though the main 6-receiver network is fully operational. There is a plan to introduce several new receivers over the next two years, which we endorse. Whilst the GPS network partnership with Dr. Mattioli has been a long and beneficial one and will undoubtedly continue, the new receivers will help MVO to move to a more autonomous footing with respect to analyses of network data by third parties. MVO should also look to making its own analysis of motions as vectors rather than line changes. Whilst we have had occasional reports of CALIPSO data at previous meetings, the dilatometer data stream should soon feed directly into MVO and we look forward to seeing MVO present these at the next meeting. Extension of the EDM network currently underway should make use of the relatively cheap reflectors now available, with purchase required. A new intriguing possibility is that spring flow rates measured from sites within the Centre Hills throughout the eruption could be related to the volcano's stress field. MVO will pursue this and we will discuss it specifically at the next meeting. Near-shore submarine discharges may also provide information of changes in the on-land groundwater regime; we recommend enquiries be made to specialist groups about possible Montserrat measurements. Several initiatives to improve the sulphur dioxide monitoring are underway, including upgrades to both the acquisition and processing software that should ease the workload and improve the signal. The issue of diminishing flux rate values with observation distance requires more investigation. The planned resumption of traverse measurements by car and boat and a new measurement site on St. George's Hill to enable gas plume tomography are good ideas and we encourage renewed consultation with Dr. Galle. We also look forward to the new soil carbon dioxide measurement results.

37. Collaborative arrangements with external groups are generally working well. Dr Calder's student was looking into the possibility of re-extracting dome survey information from the 1999-2003 photographs, which we encourage. A major new

proposal for a geo-electrical survey of the volcano had been submitted for funding from the Engineering and Physical Sciences Research Council of the UK. The SEA-CALIPSO airgun seismic tomography experiment has been submitted for funding from NERC in the UK, and the outcome will be known in November; US funding is available for field deployments.

38. At the MVO itself, the recent development of cracks, including roof leaks in several parts of the building is of concern. We understand the engineer's view is that this is a settling problem caused by foundations only being in place for months prior to building. The functioning of the Observatory is not compromised but any further cracking must be monitored.

Observers at SAC Meetings

39. Following the "Ten Years On" scientific conference in July 2005, some requests had been made by members of the public to attend the September meeting of the SAC. Whilst we want the way that the SAC arrives at it's opinions to be as transparent as possible, we declined this request to permit observers at our meetings. The reason for this is that we felt that the scope of scientific debate, and the need to explore all possible eventualities, whatever their likelihood, could be inhibited if observers are present. Freedom of thought and expression during discussions would be lost if members were worrying about how their statements and contributions might be construed and interpreted outside the meeting. The public would not be well served by mixed or contradictory messages reported by observers. We did, however, hold a public meeting in Brades on the evening of 28 September to report on the SAC meeting, to discuss recent activity, explain the Preliminary Statement issued that day and take questions from the public. Most SAC members were present at this meeting and were available to respond individually to questions. We received positive feedback at this meeting and expect to repeat this process next time.

SAC Membership

40. Dr. Rowley has resigned from the SAC because his substantive political duties were preventing attendance. His valuable contributions will be greatly missed. Professor Cashman has agreed to serve on the SAC, though she was not able to attend on this occasion because of teaching duties.

Next SAC Meeting

41. The resumption of lava dome growth could mean rapid changes in the hazard potential. Hence we judge it best to continue with our current rate of meetings. The next meeting, SAC6, should be held on 27-29 March 2006.

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

This document outlines the main responsibilities of the newly constituted 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 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
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Appendix 2: Scientific Advisory Committee on Montserrat Volcanic Activity, Meeting 5, 26 - 28 September, 2005: Agenda

1. Previous SAC report, plan for this meeting
2. MVO Activity Report *(MVO OF Report 04/05)*
3. Future scenarios of continued dome growth
    a. Lower Belham Valley pyroclastic flows
    b. Stability of crater walls/old dome remnants
4. Re-evaluation of the SO_2 criterion for end of eruption *(paper)*
5. Gas plume hazards *(paper)*
6. Long-term prognosis
    a. 1-5 years
    b. 5-20 years
7. Eruption hazard scenarios elicitation
8. Risks in Former DTEZ
9. Work/Visit-specific Risk Assessments
    a. St. George's Hill 24hr
    b. Plymouth jetty working
    c. Plymouth tourist visits
    d. Trant's quarrying
    e. Maritime Exclusion Zone
10. MVO Matters
    a. Staffing
    b. Helicopter
    c. Monitoring
    d. Collaboration
11. SAC Matters
    a. Membership
    b. Observers
    c. Frequency of meetings/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
Dr. S. Loughlin	Director, MVO
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
(Prof. K.V.Cashman	University of Oregon, USA , unable to attend)

MVO Scientists present in an advisory capacity:

Dr. R. Luckett

Dr. G. Ryan

Mr. M. Strutt

Mr. T. Sayers (part of the time)

Ms. V. Bass (part of the time)

Appendix 4: SAC5 Preliminary Statement issued 28 September 2005

During the first week of August 2005 a lava dome began to grow in the crater, following a period of increasingly vigorous ash emission and explosions that began in June. This was the first extrusion of lava in two years, following the giant collapse of July 2003. It confirmed our belief expressed in recent SAC reports that the volcano was still capable of renewed dome growth. This resumption of dome growth represents the start of the third episode in ten years.

MVO observations indicate that the rate of lava extrusion is less than one cubic metre per second. This low rate was anticipated in the last SAC report. This rate could increase as it did in 1995-97. The rate of extrusion is important for several reasons. If the rate is maintained at this low level it suggests that the forces driving the eruption are lower than in the two previous episodes. A low extrusion rate also reduces the likelihood of explosions and extends the period during which the dome is confined within the crater.

At the current rate of growth it would take well over two years for the dome to overtop the crater rim and become a potential threat. The renewal of dome growth at this rate does not significantly increase the present overall level of risk to the people of Montserrat calculated six months ago.

We have also assessed the levels of gas, based on recent measurements, such as would be experienced by people in the former DTEZ, and tourists and workers in Plymouth. These levels, on occasion, appear to exceed World Health Organisation guidelines. The full report on the hazard and risk assessment will follow.

Appendix 5: Notes from impromptu meetings of the SAC at the "Ten Years On" conference on 24 and 27 July 2005

Present on 24 July: HE D. Barnes-Jones, R. Jarvis, W. Aspinall, J. Neuberg, R. Robertson, B. Voight, G. Wadge, S. Loughlin, G. Ryan, R. Luckett, M. Strutt.

Dr Loughlin summarised the activity at Soufrière Hills Volcano since 13 June 2005. This renewed activity following the 15 April event followed a storm during which a NNE-trending fracture was formed. Following this there had been a series of four explosions on 28 June, 3, 9 and 18 July involving ash columns from 7-10 km, collapsing-column pyroclastic flows down Tar River Valley and some overflows down Tyer's Ghaut. The ash contained no pumice (unlike the resumption of the 1999 activity) and petrographic analysis by Dr J. Devine suggested that until late June the ash consisted of old andesite fragments with an assemblage of geothermal minerals with minor amounts of glassy fragments that could represent devitrified new magma glass, indicative of "old" material filling the conduit. Deformation measurements were displayed mixed signals with the Hermitage station moving towards the crater whilst more distant stations showed continued extension. Seismicity was relatively low (compared to 1995 and 1999) but had increased since June 13 with a general pattern of VTs with hybrids before and after the explosions.

Various interpretations of these observations were discussed. The explosions are an indication of the clearing of obstructions in the central conduit. The early phreatic activity was more indicative of the interaction of groundwater with residually hot rocks but the more recent progressively increasing vigour of the activity suggested a rising magma column. It was felt that the emergence of new lava at the surface in the near future was a possibility, and that if this did happen it would most likely be at a low extrusion rate.

The need for a helicopter support and an observation site on the crater at Perche's was endorsed. The time to receive preliminary petrographic reports on ash samples was about three days, though fuller reports took much longer.

Present on 27 July: HE D. Barnes-Jones, CM J. Osborne, R. Jarvis, H. Tuitt, G. Wadge, W. Aspinall, B. Voight, J. Neuberg, R. Robertson, S. Loughlin

It was affirmed by SAC members to HE and the CM that the recent activity, including the explosion on 27 July which had occurred during the conference, were an indication that the volcano was increasingly active and that the chances for continued explosive activity or resumed dome growth had much increased. It was also stressed that there was no immediate cause for new precautionary measures to be taken.

Appendix 6: 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.

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 7: 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.