SCIENTIFIC AND HAZARDS ASSESSMENT OF THE SOUFRIERE HILLS VOLCANO MONTSERRAT

First Report of the Scientific Advisory Committee on Montserrat Volcanic Activity

Meeting held 5th – 7th May 2003 at the Montserrat Volcano Observatory, Montserrat

Part I: Main Report

Issued: 20 June 2003

Executive summary

i. *The first meeting of the new Scientific Advisory Committee on Montserrat Volcanic Activity took place at the Montserrat Volcano Observatory from 5 – 7 May 2003 for the purpose of evaluating the state of the Soufrière Hills volcano and to assess volcanic hazards and risks on Montserrat.*

ii. *This Report, which is presented in two parts, records the discussions and findings of the committee, based on detailed consideration of recent activity at the volcano, and technical analyses of potential hazard scenarios.*

iii. *Given the continuing growth of a very large dome that might produce collapses of lava capable of generating pyroclastic flows which could easily reach the lower Belham Valley, the committee focussed on this threat in particular. A quantitative risk analysis indicates that the area that was evacuated in October 2002 continues to be exposed to HIGH risk on the Chief Medical Officer's scale, and that this risk level has increased since the last MVO risk assessment update, which was undertaken in January 2003.*

iv. *The Committee also considered whether the hazard line that had been recommended in September 2002 for the north side of the Belham Valley vicinity needs adjustment, and concluded that a change is not necessary at this stage. However, if the dome continues to increase in size over the coming months, more modelling work will be needed to give reassurance that areas adjacent to this boundary are not becoming vulnerable to pyroclastic flows and surges from dome collapse. For the currently populated area which extends from the 9th October 2002 'Entry Zone' boundary to Nantes River, the individual risk exposure is currently evaluated to fall in the lower half of the MODERATE category on the CMO's scale.*

v. *Risk levels are strongly dependent upon which areas are populated at the time of any volcanic activity. Reduction in societal exposure, and minimising of individual risk exposure locally, can be achieved by incremental evacuation of neighbourhoods in or bordering those areas most at threat. However, in situations where the general public is potentially exposed to a major hazard and there is a spread of scientific* *opinion concerning the threat, the Precautionary Principle is often applied to quantitative risk assessments: this entails making calculations about the influence that scientific uncertainty can have on the estimation of risk. The evaluation of plausible variations in risk estimates, because of scientific uncertainty, provides a basis for civil decision-makers to adjust their risk mitigation plans accordingly.*

vi. *While the current situation at the volcano might prevail for months without a major collapse, there have been a number of instances of intense rainfall triggering avalanches from the dome. It is judged that there is an increased likelihood of such an event occurring during this hurricane season, and that a large collapse, if it occurs, might be directed down Tuitt's Ghaut (with only marginal effects in the Belham Valley) or, more likely, into the Tar River Valley. A major collapse away from the north or northwest flanks, large enough to remove the main growing part of the dome, would alleviate substantially the threat to the Belham Valley. However, as long as the present mass of dome material remains perched above the northern and northwestern flanks of the volcano, the danger of a very substantial and energetic collapse entering the Belham Valley will persist.*

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First Report of the Scientific Advisory Committee on Montserrat Volcanic Activity - Part I: Main Report

Introduction

1. The first meeting of the Scientific Advisory Committee on Montserrat Volcanic Activity took place at the Montserrat Volcano Observatory from 5 – 7 May 2003 for the purpose of evaluating the status of the Soufrière Hills volcano and to assess the hazards and attendant risks. The Committee was commissioned by the Foreign and Commonwealth Office (FCO) and operates under the Code of Practise for Scientific Advisory Committees issued by the Office and Science and Technology (OST) in December 2001. The Committee replaces the Risk Assessment Panel, which has carried out regular assessments of the volcano in co-operation with the Montserrat Volcano Observatory (MVO) since December 1997. Terms of Reference for the Committee and a membership template are provided in Appendix 1, and the Terms of Reference for the meeting are given in Appendix 2.

2. Those who attended the meeting were: Prof. R.S.J. Sparks (SAC - Chairman), Dr. W.P. Aspinall (SAC), Dr. P.N. Dunkley (MVO), Dr. M. Edmonds (MVO), Dr. J.-C. Komorowski (Institut de Physique du Globe de Paris - IPGP), Dr. J. Neuberg (SAC), L. Rodriguez (MVO), Dr. K.C. Rowley (SAC – present for part of the meeting), Dr. G. Thompson (MVO), Dr. R.I. Tilling (US Geological Survey - USGS), and Prof. G. Wadge (SAC – present for part of the meeting). A list of the participants and their affiliations is provided in Appendix 3. It is noted that Dr R. Tilling (former Director of the Volcanic Hazards Program of the USGS) and Dr J.-C. Komorowski (IPGP and former Director of the Guadeloupe Volcano Observatory) attended the meeting as independent observers at the invitation of the Governor of Montserrat.

3. This report[1] summarises activity of the volcano as recorded by MVO and takes account of new data and concepts developed from monitoring and research work since the last MVO Hazards and Risk Assessment Report was prepared, in September 2002. The hazards are assessed and, where necessary, the findings of the September 2002 assessment and the two Addendum Reports to that assessment issued in November 2002 and January 2003 are modified.

4. The form of this report is divided into two parts. Part I records the main findings, and Part II[2] provides a report of technical aspects of the assessment, including an addendum (Appendix 1) which outlines some important generic limitations to this approach (and should be read in conjunction with this document). Matters discussed that were unrelated to the assessment itself, such as the constitution and procedures of the Committee are recorded separately in the minutes of the meeting.

5. The Preliminary Statement issued on 12 May 2003, shortly after the meeting concluded, is included in Appendix 4. A glossary for readers unfamiliar with basic terminology and concepts in volcanology is provided in Appendix 5. In the Main Report assessment of levels of risk are given on the Chief Medical Officer's (CMO) Risk Scale, which is summarised in Appendix 6. The risk analysis and hazards scenarios are described in the Technical Report.

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[1] The information provided in both parts of this Report is advisory. It is offered, without prejudice, for the purpose of informing the party commissioning the study of the risks that might arise in the near future from volcanic activity in Montserrat, and has been prepared subject to constraints imposed on the performance of the work. While Panel members believe that they have acted honestly and in good faith, they accept no responsibility or liability, jointly or severally, for any decisions or actions taken by HMG or GoM or others, directly or indirectly resulting from, arising out of, or influenced by the information provided in this report, nor can they accept any liability to any third party in any way whatsoever. See also Appendix 1 of Part II of the Report.

[2] Scientific and Hazards Assessment of the Soufrière Hills Volcano Montserrat. First Report of the Scientific Advisory Committee on Montserrat Volcanic Activity, 5 – 7 May 2003: Part II: Technical Report, issued 20 June 2003.

Volcanic activity

6. The eruption of the Soufrière Hills volcano has involved three main phases, as summarised in a chart of volume of magma erupted against time (Figure 1). The first phase of the eruption, from July 1995 to March 1998, consisted of growth of a lava dome accompanied by several hazardous phenomena, including pyroclastic flows, explosive activity, a major volcanic landslide and associated volcanic blast, ash fall, and volcanic mudflows. This phase included a particularly vigorous period of activity from May 1997 to March 1998 when the rate of eruption of magma was approximately double the average rate for the eruption as a whole. The second phase of the eruption from March 1998 to November 1999 consisted of residual volcanic activity in which dome growth ceased, but hazardous activity continued, including dome collapses with pyroclastic flows, explosions, ash and mudflows. The third phase of the eruption began in November 1999 with the resumption of dome growth and continues at the time of writing this report.

7. The meeting focussed its attention on the third phase, which is described in the MVO Open File Report 1/03, prepared specifically for the meeting. The third phase of the eruption has been characterised by almost continuous extrusion of lava at an average rate slightly more than 2 cubic metres per second (Figure 1). It has also featured some fluctuations of extrusion rate, including limited periods (up to several months) of very low or no growth, and some periods of heightened activity, such as the three weeks either side of Christmas 2002 when many pyroclastic flows reached the sea on the east coast. There have been two large collapses of the dome in this phase: on 20 March 2000 (20 million cubic metres) and 29 July 2001 (45 million cubic metres). In each case pyroclastic flows moved down the Tar River into the sea and a large collapse scar was formed in the dome. These large collapses were both associated with exceptionally intense rainfall, which is thought to have destabilised the dome (see Part II).

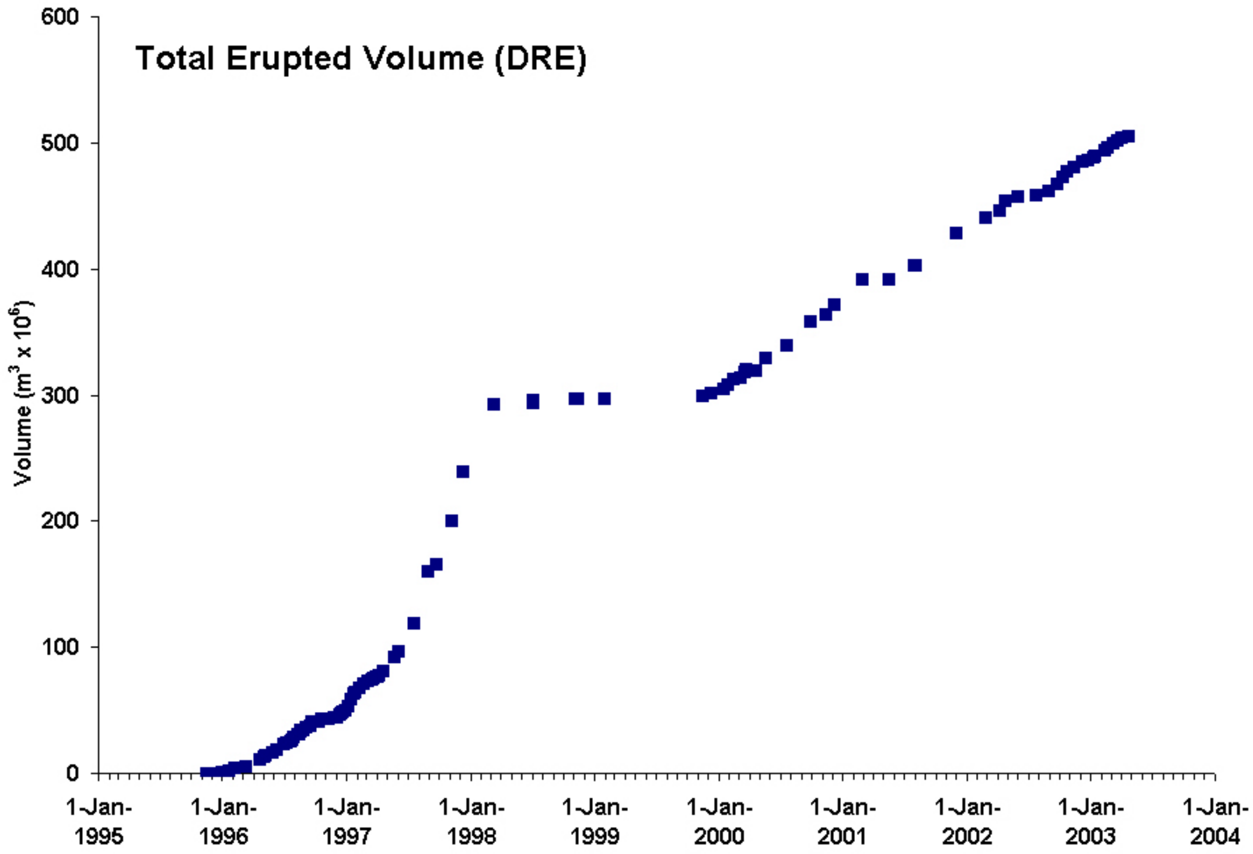

Figure 1 Cumulative erupted volume of magma at Soufrière Hills volcano: 1996 - 2003

8. The third phase of the eruption has not been as explosive as the first phase in 1997. While the large collapse of 29 July 2001 was accompanied by two short-lived explosions, it did not generate a volcanic blast and was not followed by a period of repetitive explosive activity. The third phase has also been characterised by large numbers of rockfalls and by occasional dome collapses that have generated pyroclastic flows of sufficient size and energy to reach the sea at the east coast.

9. Monitoring data have established the following features of the third phase. Seismicity is dominated by rockfalls from the growing dome and by long period earthquakes with typical rates of hundreds of events per week. Ground deformation data show that the volcanic edifice expands during periods of no or low lava extrusion, and contracts during periods of lava extrusion. These observations are consistent with pressure fluctuations in a substantial magma reservoir at depth beneath the volcano. Sulphur dioxide emissions of several hundred tonnes per day, high ratios of sulphur dioxide to chlorine, earthquake depth data, ground deformation data and petrological studies are all consistent with magma pooled at depths of 5 km or more, which is being continuously supplied by new magma from deeper in the Earth. The near steady-state extrusion of lava for three-and-a-half years implies a substantial magma system - and there is no evidence for any decline in supply.

10. Since the last full assessment in September 2002 continued magma extrusion has increased the size of the dome. It is now the largest it has ever been since the eruption began, with a volume of over 200 million cubic metres (Figure 2). The active summit of the dome has an altitude of about 1090 m above sea level, and one recent spine of lava reached 1163 m above sea level. The highest point on Montserrat before the eruption was Chances Peak at 914 metres above sea level.

11. A characteristic pattern of dome growth behaviour has been recognised by MVO from observations and monitoring data. The dome commonly grows in a particular direction for periods of a few weeks to a few months. Such directional extrusions tend to stagnate and then there is a new surge of magma (sometimes marked by changes in seismicity or gas emission rates) that extrudes out in a different direction. The larger and more energetic collapses and associated pyroclastic flows are commonly associated with such switches. In these cases, pyroclastic flows and rockfalls are predominantly in the direction of growth, and involve material avalanching from high on the dome. Over the last 8 months there have been five such changes in growth direction.

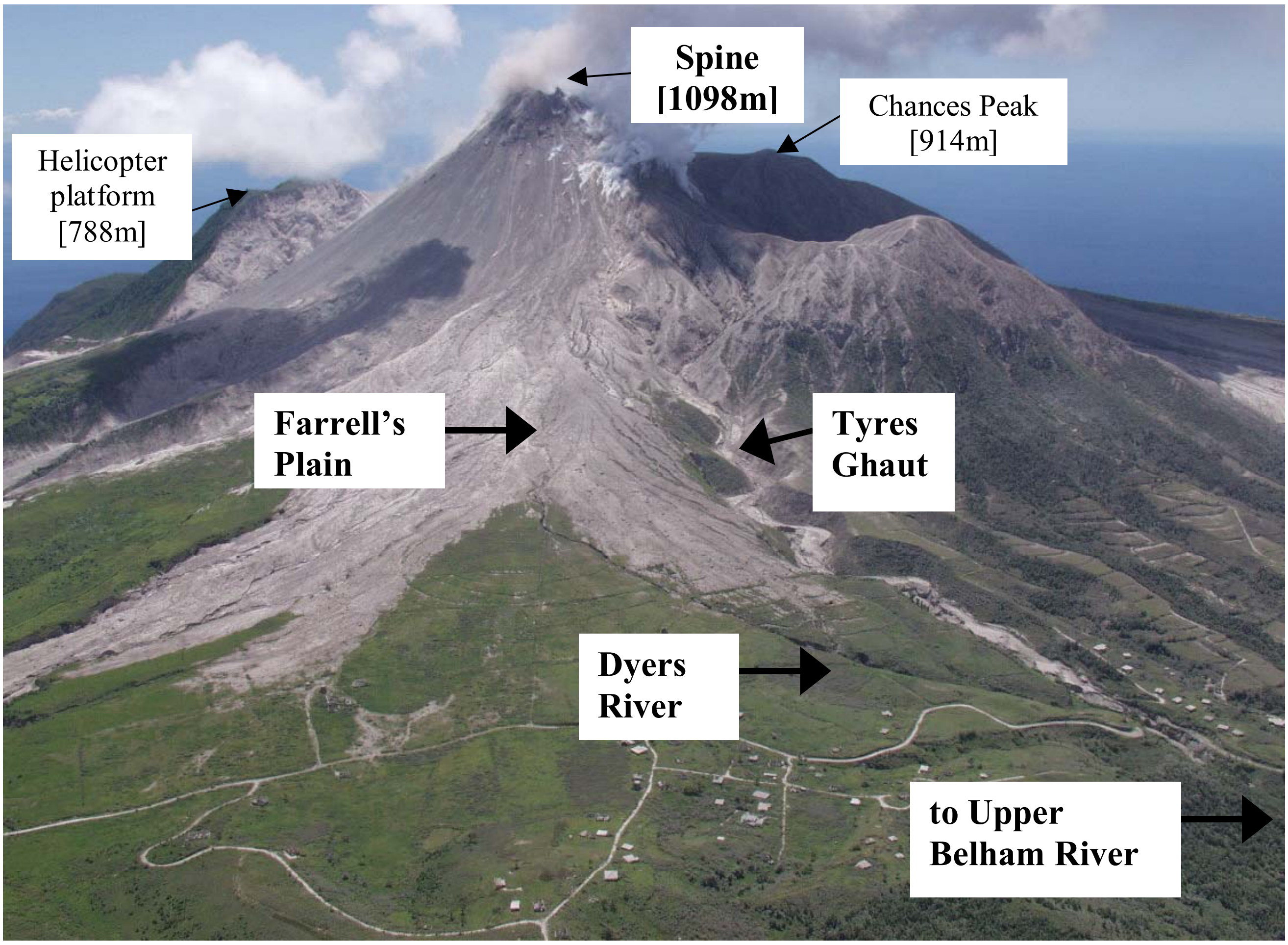

Figure 2 View of north flanks of Soufrière Hills volcano - May 2003, showing features mentioned in text, and heights above sea level (photo courtesy MVO)

12. Collapses can also be triggered by intense or prolonged heavy rainfall. In this case, the direction of collapse is not thought to relate to growth direction, as for example the 29 July 2001 collapse, which occurred towards the east at a time when the dome was growing towards the south. Observations suggest that talus on the lower flanks of the dome can be eroded vigorously, and this erosion can progressively undermine the dome, generating major collapses.

13. The Committee noted the observation of a remarkable phenomenon on 18 and 19 December 2002, when mudflows occurred in several ghauts, including the Dry Ghaut. This activity was not preceded by any significant rainfall in the previous days and weeks, and is thus interpreted as significant incident involving internal processes within the volcano. Unexpected discharges of muddy water, unrelated to rain, have been observed on other volcanoes (e.g. Mont Pelée in April 1902, and Mount Usu, Japan in 2000), as well as an earlier episode on Montserrat in July 1995. However, in all previous cases the discharges occurred prior to eruption. The most recent instance on Montserrat is of a kind that has not been recorded elsewhere before, to our knowledge. While the associated mudflows can be hazardous in their own right, a transient phenomenon such as this highlights the fact that internal conditions in this volcano can change suddenly - and the volcano therefore maintains its capacity to do the unexpected.

Volcanic hazards assessment

14. From a hazards perspective the main concern in this report is the generation of pyroclastic flows that might affect populated areas and influence administrative decisions on the boundary of the Exclusion Zone. The most important hazards issue therefore is in relation to collapses of the dome that could result in pyroclastic flows reaching the lower parts of the Belham Valley and adjacent populated areas. Collapses of the dome to the north, northwest and west might generate pyroclastic flows and associated surge clouds of sufficient size and energy to affect these areas. The margins of the Belham Valley were evacuated on 9th October 2002 due to growth of the dome towards the north and northwest. The authorities used the hazards line defined at the September 2002 RAP meeting (Figure 3) to define an administrative boundary to the Exclusion Zone. The hazards were assessed by the Risk Assessment Panel and MVO in November 2002 and again in January 2003 as remaining high in the lower Belham Valley. An important task of the SAC meeting was to evaluate whether the level of hazard had changed since.

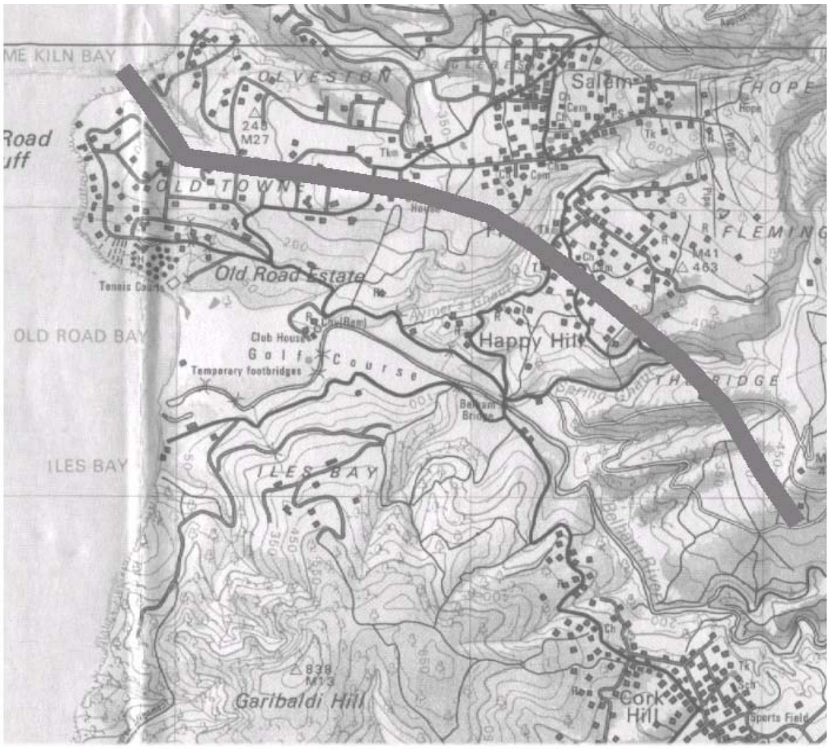

Fig. 3a   Pyroclastic flow and surge hazard line north of the Belham River Valley: this line separates areas likely to be affected by hazards from flows and surges in the valley, if they occur, from areas at lower risk (see text) *n.b. this line does not define the official risk boundary, which is set administratively (see Fig. 3b)*

Fig. 3b   Map showing administrative Entry Zone boundary (blue line) and area evacuated (light blue hatching) on 9 October 2002

15. The principal hazard in the Belham Valley is a collapse of the dome in a direction that will cause pyroclastic flows to reach the lower parts of the valley. The nature of the threat is illustrated in the photograph of the dome shown in Figure 2. Continuous growth since August 2002 has had three important effects. First the volume available for collapse of the dome to the north or northwest has increased so that the dome has greater potential for larger collapses. Second the height of the dome has increased so that the potential energy of a collapse of a given size has increased. Third the growth of the dome and its talus slope to the north has changed the topography (see Part II for details) such that the proportion of the dome that could collapse directly into the Belham Valley catchment has increased. All these factors increase the hazard in comparison to the situation in September 2002 and when the evacuation was called on 9th October 2002. Additionally, part of the old remnants of the 1997 dome, buried under the active dome on the northern flanks, have been a site of hydrothermal alteration, in which the rock may have been altered to soft clays and similar products by reaction of the rock with steam and other hot reactive volcanic gases, leading to a concern that this flank may be being weakened.

16. The volume of available material above an altitude of 930 metres was estimated as about 14 million cubic metres; this is the volume of the active dome that is freely available to collapse in any direction. (In the last 8 months, no collapse has approached this volume of material - the largest was 2 October 2002, involving 7-8 million cubic metres). Thus the conditions for collapses with volumes in the range 3 to 10 million cubic metres exist.

17. Collapses of the dome can occur with little warning. Pyroclastic flows with volumes above 3 million cubic metres travel at speeds of tens of metres per second and are estimated only to take 2 to 3 minutes to travel from the dome to the lower Belham Valley. Persons within the Belham Valley would very likely be killed or seriously injured if such an event were to occur.

18. Some members of the SAC and colleagues (see Part II) have applied quantitative models to evaluate the run-out of collapses of 3 million cubic metres or more in a north or northwest direction: these are very likely to travel past the Belham bridge locality and possibly affect the area that was evacuated on 9th October 2002. A collapse of 10 million cubic metres is likely to reach the sea at Old Road Bay with associated surge clouds rising tens of metres up the margins of the valley. For collapses in the range 3 to 10 million cubic metres by volume, the hazard line drawn in September 2002 was assessed as remaining appropriate. This line provides the scientific basis for the administrative line that defines the Exclusion Zone established on 9th October 2002 (see also Part II – Technical Report).

19. Growth of the dome directed to the north or northwest provides circumstances that favour pyroclastic flows entering into the Belham Valley. Topographic changes on the northern flanks have increased the sector the dome that has access to Tyre's Ghaut, which leads into the Belham Valley. With a large talus slope now built on the northern flanks, collapses triggered by rainfall and unrelated to growth direction are also possible in this sector. It is judged that there is an increased likelihood of such an event occurring during this hurricane season.

20. Over the last several months since the evacuation there have been numerous occasions when rock falls and small pyroclastic flows have travelled across the Farrells Plain or down Tyre's Ghaut. On 8th November 2002, a pyroclastic flow reached Dyers Bridge, a distance of 2 km down the upper Belham Valley. Several small pyroclastic flows have taken this route since January 2002. It should be recalled that on 25 June 1997 small pyroclastic flows derived from the main pyroclastic flows were diverted down Belham Valley and reached Cork Hill. In early August 1997, pyroclastic flows from explosions reached a similar distance. Since the recent SAC meeting in early May 2003, pyroclastic flows have travelled to the north, on 13 and 14 May 2003. There is thus unequivocal evidence that this is a pathway that can capture flows. It will only take a collapse of 3 million cubic metres or more

(1.5% of the current dome volume) for a flow to travel to the areas evacuated on 9th October 2002.

21. The Committee considered the possibility of significantly larger collapses (in excess of 10 million cubic metres) that might have the potential to affect areas outside the current Exclusion Zone. In September 2002 it was judged that the dome was not yet sufficiently large for such collapses to be very likely. In the 8 months since that assessment the dome has increased in volume by 5-6 million cubic metres above the 930 metre level, and by as much as 20 million cubic metres above the 800 metre level. The volume of the dome available for collapse above an altitude of 800 metres above sea level was estimated at 40-45 million cubic metres. (This altitude was chosen as it approximately represents the northern rim of English's Crater Wall above Tyre's Ghaut).

22. A major uncertainty in assessing the potential for a much larger collapse to the north concerns the stability of the remnants of the 1997 dome-building activity. A remnant of the dome known as the central buttress exists on the northern flanks. Following the major collapse of 29 July 2001, the latest dome built itself up behind this remnant and has now completely buried it. The remnant and the area around it has been notable for strong fumarolic activity, and the present surface of the dome, in front of this buried remnant, is now characterised by strong steaming. Such activity can weaken volcanic rocks. Thus, there is concern about the possibility of a major collapse involving this remnant. Further modelling work and appraisal is required to evaluate the mechanisms and likelihood of larger collapses to the north, and to provide reassurance that the position of the current hazard line is adequate. The MVO has determined that this work should be carried out.

23. In view of the dome having reached its greatest ever volume, standing at over 200 million cubic metres, the Committee felt that they should also examine the implications of a much more substantial collapse of the dome than any hitherto experienced: given that previous major collapses in Montserrat had involved as much

as 50 – 60% of the available material in a dome, a collapse entailing perhaps 100 million cubic metres in total should be considered. Although there are no well-documented cases of unequivocal dome collapses this big, there are some known flow deposits in Chile, Kamchatka and the USA that indicate collapses of this size can occur. Also, there is new evidence from research carried out around Montserrat by the Institut de Physique du Globe of several very large landslides into the sea in the recent geological past. However, the Committee felt a collapse of such magnitude from the Soufrière Hills volcano is plausible only through the lowest part of the crater area under present conditions, that is, out to the northeast through the Tar River area. The Committee also noted that long-term monitoring of ground deformation at the Hermitage site, 2 km east of the dome, shows that this site has been moving outwards continuously to the east-northeast since measurements began there; the forcing mechanism is not fully understood, but the movement provides evidence that the eastern side of the volcano is not stable.

24. Whilst a collapse on this scale of much of the present dome was still assessed as having a low probability of occurring (see Part II), it is certainly not implausible and thus continued vigilance is necessary by MVO. The possibility that a collapse of this size might take place as a sudden, short-duration event would raise additional concerns about tsunami hazard in the region, based on the work of Heinrich et al.[3].

25. The Committee noted that in the event of a hurricane or large tropical storm the likelihood of a major (rain-induced) dome collapse is heightened. During severe weather an evacuation of areas close to the margins of the Belham Valley would be very difficult. The authorities might therefore consider putting in place measures for short-term precautionary evacuations of areas south of the Nantes River; the duration of such an evacuation need only be as long as the severe weather condition is going to last (typically 1-2 days).

[3] Heinrich et al., (1999) Numerical modeling of a landslide-generated tsunami following a potential explosion of the Montserrat volcano. Physics and Chemistry of the Earth, A, 24, 163-168.

26. The present situation at the volcano, with a large mass of dome material perched above the northern and northwestern flanks, might prevail for months without a major collapse occurring. The topography of the dome can change again, and switches in its direction of growth may take place. Nevertheless, until a major change takes place (e.g. a very large collapse down Tar River Valley), or growth ceases and the dome stagnates for a very long period of time (it will need many years to stabilise), the present configuration will remain ripe for a very substantial and energetic collapse, which could be triggered by an internal magma extrusion pulse or heavy rainfall. Such a collapse could involve dangerous flows and surges in the Belham Valley.

27. As noted previously, however, (e.g. MVO Hazards and Risks Second Addendum Report, 31 January 2003), the committee emphasises that this assessment is not predicting that a major collapse is necessarily going to occur in the near future nor, if one does occur, that the bulk of the material involved will inevitably go down the Belham Valley. Indeed the more likely outcome is that the present threat, with the accompanying *HIGH* risk level in the Belham Valley, will remain until conditions are changed by a future event. A large collapse, if it occurs, might be directed down the Tuitt's or Gages sectors, with only marginal effects in the Belham Valley. It is also possible that a rainfall-triggered collapse which was large enough to remove the growing part of the dome in some other direction, for instance down the Tar River Valley, could alleviate substantially the threat to the Belham Valley.

28. Also, while this report places emphasis on the hazards associated with dome collapse and pyroclastic flows, other potential hazards remain: during dome collapses with unfavourable wind directions there can be heavy ash fall in the populated areas; explosions accompanying or following a major dome collapse can result in rock fragments up to a few centimetres in size falling in the populated zones; periods of intense rain can cause volcanic mudflows and make areas like the Belham Valley highly hazardous. Or, if the volcano were to return to the high levels of activity that characterised the eruption from May 1997 to March 1998 then the situation could

revert to one in which vigorous explosive activity and generation of violent volcanic blasts become more likely.

29. In considering this assessment, the authorities are reminded that scientific recognition of a change in the state of the volcano to a much more dangerous condition might emerge in only a matter of hours or less before the occurrence of a hazardous event. Thus, although the arrangements for mitigation and evacuation of the populated areas near the current Exclusion Zone are not the responsibility of the scientific team, the SAC committee emphasizes that the risks to people in these areas could change with very short notice.

Long-term prognosis

30. The eruption has now continued for nearly eight years. Based on an analysis of historic dome eruptions worldwide, first presented in Appendix 7 of the MVO Hazards and Risk Assessment of March 2002, the statistical indications are that there is only a 3.2% chance that the current eruption, having persisted for 94 months, will stop within the next 6 months; a 50% probability that the eruption will last a further 14 - 15 years, and a 5% chance that the duration could exceed 180 years in total duration. This interpretation of the pattern of dome-building eruption durations is derived from the global experience data, and can provide only rough guidance as to the likely behaviour in the individual case of the current dome eruption of the Soufrière Hills volcano.

31. The Committee noted, however, that there was a good correlation between the rate of eruption in Montserrat and ground deformation behaviour: when the dome is growing the ground deflates, and when the dome is not growing the ground inflates. This evidence is consistent with a source of magma supplying the eruption that is being continually pressurised. Together with gas evidence the simplest explanation of the observations is that the reservoir is being supplied by new magma from much deeper

in the Earth. As long as this deep supply continues then it is very likely that the eruption at the surface will continue. There are no signs yet of any decline in the magma effusion rate, which has been quite sustained, albeit with minor fluctuations, since November 1999. A more technical discussion of these matters is summarised in Part II. Taken together, all the available evidence points to a persistent eruption that is likely to continue for many more years and perhaps decades.

32. However, long-lived dome eruptions can also switch into more dangerous styles of activity at any stage. Highly hazardous events can occur after many years or decades of effusive activity. For example, the dome eruption of Bezymianny, which started in 1956, had a violent volcanic blast in 1997, and Lascar volcano in Chile had a major explosive eruption in April 1993 after nine years of dome growth in the crater. These incidents demonstrate that, like any erupting volcano, the Soufrière Hills will need to be carefully monitored while it remains active.

Present risk exposure on Montserrat from volcanic hazards

33. The volcanic hazards identified above are used as the basis for undertaking a quantitative assessment of the risk exposure to people living on Montserrat. The detailed results of that assessment are presented in Part II of the Report, with the overall societal risk levels being expressed in terms of the probability of exceeding a given number of casualties in a certain time period (6 months).

34. In qualitative terms, the societal risk levels that are currently associated with the identified hazards are slightly lower for small numbers of casualties (i.e. 1 to 5 fatalities) than those that were produced in the January 2003 update, but slightly higher for larger numbers (i.e. 15 or more casualties). The main reason for this minor change in balance is that the hazard assessment elicitation has taken into account the most recent behaviour patterns of the volcano, slightly reducing the expected

frequency of occurrence of some of the classes of 'small' hazards and, hence, the corresponding chances of these affecting the populated areas.

35. The assessment has also recognised that, with an ever larger dome, a long elapsed time since the last major collapse, and an on-coming rainy season, the chances of experiencing one of the classes of much bigger pyroclastic flows are marginally elevated, and flows of these sizes have the capacity to affect wider areas, further away from the volcano, and hence impact larger numbers of people.

Risk to particular places as requested by HMG

36. General. The Terms of Reference for the meeting provided by HMG made some requests for risk assessments of some very specific and some quite small areas. The Committee remarked that discrimination of the hazard and risk levels between close neighbouring areas is very difficult, and in many cases well beyond the knowledge and understanding of the processes and uncertainties. The hazard line defined in the September 2002 assessment was based on judgements of how far surge clouds from pyroclastic flows entering the lower Belham Valley might reach (see Part II). The basis of the line is that it represents distances from the valley centre and heights above the valley floor that go a little beyond the distances and heights that have been observed to have been affected (elsewhere on Montserrat) by surges during the eruption.

37. Although both the hazard and risk decrease away from the valley margin, there is only a limited margin of safety involved in the present location of the line. Given the uncertainties involved, the group do not think it is possible to make minor adjustments to the line on any scientific grounds. The hazard line was intended to be used as guidance for drawing an administrative boundary to the current Exclusion Zone by the authorities (i.e. for the choice of official zoning). The Committee of

course recognises that many other, non-scientific, factors will affect where administrative lines are drawn in detail.

38. In the following account, levels of risk are reported using the Chief Medical Officer's Risk Scale. Where appropriate, numerical values of risk and related technical matters are recorded in Part II of this report. The reader should note that the reason for adopting this broad scale is that the risk estimates must be regarded as having large uncertainties and there is no justification for attributing meaning to small differences in estimated risk from one evaluation to another, or between closely neighbouring areas. In most respects, the volcanic risks of concern here are best considered within broad categories that can be compared with other kinds of risk. Because HIGH is the highest category on the CMO's scale, once the risk in question has reached this level it cannot be expressed any more strongly (except by further subdividing the category, for which there is no precedent in the present context).

39. Assessment of risk for the Belham Valley Exclusion Zone compared with the September and January assessments if the population were to return. The level of hazard has increased in this area due to the increasing size of the dome and potential for large collapses. This assessment is reflected in the equivalent levels of societal and individual risk that are obtained for this area, with the individual risk exposure being HIGH in terms of the CMO's scale. In quantitative terms the individual risk exposure has increased by a factor of 1.6 over the corresponding risk estimated in January 2003. If, however, the dome growth direction switches and is directed consistently to the north or northwest in the near future, the risk would become even greater.

40. Risk to those entering the E.Z. 9-1400 Hrs with existing mitigating measures. For the present assessment, the effects of existing mitigation measure were discounted for two reasons. First, because a large collapse of the dome could happen with little warning and could take less than 3 minutes for a large flow to reach the sea at Old Road Bay - in these circumstances any mitigation measures are unlikely to be

effective. Second, because the incorporation of administrative mitigation measures into a risk assessment requires assumptions about how effective, timely and dependable such measures might be. The Committee did not feel it had enough information to make reliable assumptions about such measures. Given these restrictions, the level of individual risk for someone spending about 30 hours per week in this area is judged as MODERATE, as before, but again there is a significant numerical increase associated with the underlying quantitative risk estimate and at the 84%ile level in the spread of scientific uncertainty, the numerical risk comes out very close to the boundary with the HIGH category.

41. Risk to E.Z. 9-1400 extending to daylight hours. For someone spending about 12 hours per day, six days per week, in this area, the individual exposure falls on the boundary of MODERATE to HIGH risk.

42. Risk in Isles Bay. The risk in this area is evaluated as the same as the Belham Valley area evacuated on 9th October 2002, that is, HIGH for permanent occupation, and MODERATE for authorised entries not exceeding 30 hours per week.

43. Risk in the old Day Time Entry Zone. The individual risk for anyone in this zone for more than a few hours per week is HIGH.

44. Risk in outer northern fringes of EZ in area Ministers propose to free up (the Lowell Lewis Line) and also risk in the open area directly abutting the Exclusion Zone. This matter concerns very small areas at the fringes of the Exclusion Zone, and the position of the volcanic hazard line that was recommended in the last risk assessment. While a hazard line such as that shown in Fig. 3a is the best judgment of experienced volcanologists, it is not possible to discriminate between levels of attendant risk over distances of a few tens of metres either way, given the scientific uncertainties and inexact assumptions underlying the related quantitative risk estimation, and given the intrinsic natural variability of volcanic phenomena. That said, it would be very

difficult to put forward any scientific case for moving the line closer to the volcano at the present time, given the size and state of the dome.

45. Risk (societal and individual) in the area from the EZ boundary to Nantes River. These areas sit adjacent to the Belham Valley and could become vulnerable to a very large collapse of the dome. The Committee considered whether the current hazard line needed adjustment at this stage and concluded that this was not necessary. However, if the dome continues to increase in size over the coming months, more modelling work will be needed to give reassurance about the vulnerability of this area. More details on this issue are given in paras. 15 - 17 above, and in Part II. At the moment, the individual risk exposure in this area is currently in the MODERATE category, taking the area as a whole (individual risk would be less in the more northerly parts, and higher closer to the volcano, of course). The current quantitative risk assessment indicates that this particular area contributes a very high proportion of the risk exposure for small numbers of casualties, and a significant amount (generally more than two-thirds) to the overall societal risk for the island in its entirety.

46. Maritime Exclusion Zone. The Maritime Exclusion Zone is based on the possibility of hot clouds of ash (known as surge clouds) related to pyroclastic flows flowing across the sea. Such clouds have been observed to travel up to 2 km from the coast of Montserrat during the present eruption (and even further at eruptions elsewhere). Thus, the Exclusion Zone was originally set about 2 nautical miles off the coast (to provide a small margin of safety). The Committee noted that with an increasingly large dome and potential for even larger collapses the extent of the Maritime Exclusion Zone should be kept under review. At this stage, the Committee considers that the current extent of the MEZ remains appropriate for the time being.

Operations at MVO

47. One of the roles of the new Scientific Advisory Committee is to give independent consideration to MVO operations. The Director of the MVO therefore provided other Committee members with a briefing on developments, which are reported here.

48. The move into the new MVO was completed very efficiently by MVO staff, with fewer problems than had been expected and no loss of monitoring capability during the transition. Careful planning and execution ensured continuity of scientific data gathering and observations while the transfer took place. The new building is an outstanding facility and the direct views of the volcano have greatly improved the immediacy of monitoring of activity at the volcano. The Director reported that the building provides an excellent work environment and that the morale of the staff was high as a consequence. The Committee extended their congratulations to MVO for the efficiency and effectiveness of their move to the new building.

49. There continue to be hold-ups in the process of upgrading the seismic system. It is now nearly 3 years since the upgraded network was first proposed and approved by the MVO Board. There have setbacks for a variety of reasons, but delays in authorisation by DFID have been a significant contributory factor. Over this time the existing seismic network has managed to function, despite its deficiencies. However, the Committee noted that the system remains vulnerable to terminal failure, in which circumstances there would be a crisis. The Committee recommends that the remaining steps are taken to procure the new seismic system as a matter of urgency.

50. The MVO has improved its gas monitoring facilities further with purchase of an FTIR spectrometer for measurement of chlorine and sulphur gases. This instrument, and the data it provides, complements the DOAS spectrometer network.

51. The MVO will be focussing its attention over the next several months on further integration of datasets and software development. Some excellent progress has already been made.

52. The Committee noted that MVO remains an organisation that is often severely stretched and, given the high levels of activity at the volcano, the staffing levels are barely adequate. The Committee were concerned that the burden of responsibility and related stresses are high for senior staff. The burden of work to maintain the monitoring at a high level is considerable, leaving limited time for other tasks, such as development of hazard tools, more detailed analysis of data and outreach activities.

53. The Committee noted that the MVO currently had a policy of overseas staff working for 3 months and then being deployed to the UK on other assignments, training and periods of leave. While this policy was generally welcomed, the Committee had some concern that it appeared to be applied rather rigidly. Some flexibility is recommended; for example, if the policy remains in place it may be difficult to make sure that all the key members of MVO staff are present at hazard and risk assessment meetings, or if there were a really serious escalation of volcanic activity. The Committee also hoped that BGS would have a policy of allowing MVO staff to work on Montserrat data while in the UK. Dr Tilling commented that the USGS have a policy of longer periods of deployment in their Observatories and longer periods away working on Observatory data. He commented that in his experience the three months on and one month off might prove to be rather too short in terms of time, although the proportions of work on and off island seemed about right.

54. The Committee asked that MVO consider providing access for Committee members to the daily images from the Whites and Windy Hill cameras through the internet, as regular inspection of these images can give Committee members critical information to maintain awareness of the volcano's activity.

Future assessments

55. The Committee had a number of recommendations for future work by MVO pertinent to improving the hazards and risk assessments and in the light of the increasing size of the dome. Modelling should be carried out on larger collapses to the north to give reassurance that such larger events would not affect areas outside the current Exclusion Zone. The Committee suggested that the MVO also consider obtaining an updated topographic model of the northern flanks to assist modelling. Such a map could be obtained by photogrammetry of new aerial photographs or by lidar measurements.

56. One aspect of the work of the Risk Assessment Panel over the last few months has proved problematic. Two recent mini-assessments were commissioned, one in November 2002, and the other in January 2003. These were presented as addendum reports to the September 2002 assessment. While the reasons for these re-appraisals were understandable they proved quite difficult to undertake in practice, and the new Committee's recommendation is that the SAC is not involved in such ad hoc assessments outside the regular meetings unless quite exceptional circumstances arise. Volcanic eruptions are complex, time-varying phenomena and providing rapid yet robust analyses through a Committee working mainly away from Montserrat is difficult. There remains an issue of how hazards and risk work is carried out by MVO between the SAC meetings. There are merits in continuing to use individual SAC members as a source of expertise, but this needs some further consideration, especially concerning extent to which the BGS can provide such resources from within their contract to run the MVO. This could be a topic for discussion at the proposed meeting to be held at FCO to appraise the early activities and experiences involved in convening and launching the work of the Montserrat SAC.

57. Preparation for future SAC meetings needs to be made a number of months in advance, noting that members of the Committee have many other commitments outside Montserrat and that significant warning is required to ensure that all members

can attend the entire meeting. The unavoidable very short lead-time for this first meeting led to a number of difficulties and indeed inefficiencies. Committee members and MVO staff felt that they had insufficient preparation time. The MVO need several weeks at least to prepare a synthesis of their data. Similarly a few weeks at least are needed for the Committee Chair to discuss with the MVO and other members the key points and key information that is needed for the meeting. For instance, two colleagues had to leave before the end of the meeting and were not present on the third day. Thus additional work has been created to ensure that their views and expertise was fully incorporated into the findings and results of the assessment. Finally fixing the dates well in advance could reduce travel costs substantially.

58. The OST Code recommends that scientific advisory committees have an impartial secretariat and that minutes are recorded of meetings. Normally the sponsoring Government department provides a secretary to the Committee who attends meetings and records minutes. This was not the case for this first Montserrat SAC meeting: minutes were recorded by the chair and on the third day by one of the MVO staff during the expert opinion elicitation (see Part II). This procedure was not satisfactory as it very difficult for members of the committee and MVO staff to participate fully in the discussions and record minutes. In previous meetings of the risk assessment panel a colleague from the BGS, who was not a member of the Panel, took minutes. It is strongly recommended that the FCO provides a secretary to record minutes at future sessions. It is preferable that this person has some technical knowledge since much of the meeting is concerned with consideration of scientific data and ideas (the Natural Environment Research Council and the Health and Safety Executive are bodies with the necessary in-house expertise, for instance).

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 will be Jess Seaward, Desk Officer for Montserrat in OTD. Her contact details are as follows:

Email: jess.seaward@fco.gov.uk
Tel: +44 20 7008 3123
Fax: +44 20 7008 2879

Appendix 2: Agenda for May 2003 SAC Meeting

1. Consideration of the Terms of Reference and Membership conditions for the Committee and the meeting Agenda.

2. Synopsis of the eruption with emphasis on the period after renewal of dome growth in November 1999.

3. Activity since the last hazard and risk assessment and assessment of current activity.

4. Assessment of pyroclastic flow hazards.

5. The method of Expert Elicitation (WPA).

6. Assessment of risk (in individual and societal terms) for Belham Exclusion Zone compared with Jan/Sept assessments if population were to return.

7. Risk to those entering E.Z. 9-1400 with existing mitigation procedures

8. Risk if 9-1400 entry extended to daylight hours

9. Risk in old DTEZ.

10. Risk within Belham Exclusion Zone:

11. Risk in Iles Bay

12. Risk in outer northern fringes of EZ e.g. in area Ministers proposed to free up (Lowell Lewis boundary)

13. Probability of PF down Belham of: 3m cubic metres)
    i. 10m cubic metres) in next 6 months
    ii. 30m cubic metres)

14. Area likely to be affected in the event of PFs of above volumes.

15. Risk (societal and individual) in area from EZ boundary to Nantes River.

16. Risk in 'open' area directly abutting EZ.

17. Assessment of risks as in 1), 2) and 8) <u>if</u> growth direction switches to west above Belham (societal and individual).

18. Assessment of risks as in 1), 2) and 8) in six months time if growth continues as in the past six months (eg some fluctuation).

19. Assessment of risks as in 1), 2) and 8) in six months time if growth continues focussed away from danger area (eg away from N, NW, W).

20. Likelihood of risks in Belham E.Z. falling in next 3/6 months to levels pre-October evacuation.

21. Assessment of Risk to Existing Maritime Exclusion Zone.

22. Future hazards and risk assessment work.

23. Review of MVO monitoring programme.

24. Committee Membership

25. Any other business

4th May 2003

Appendix 3: List of participants

Chairman

Prof. R.S.J. Sparks FRS	Dept. of Earth Sciences, Bristol University, UK

Committee members

Dr. W.P. Aspinall	Aspinall & Associates, UK
Dr. P.N. Dunkley	Director, MVO
Dr. J. Neuberg	Leeds University, UK
Dr. K.C. Rowley	Trindata Ltd., Trinidad & Tobago (present for first two days)
Prof. G. Wadge	Reading University, UK (present for first two days)

MVO Scientists present:

Dr. M. Edmonds

Ms. L. Rodriguez

Dr. G. Thompson

At the invitation of the Governor:

Dr J.-C. Komorowski	Institut de Physique du Globe de Paris, France: former Director of the Guadeloupe Volcano Observatory
Dr. R.I. Tilling	US Geological Survey, USA: former Director of the USGS Volcanic Hazards Program

Appendix 4: Preliminary statement of the Assessment carried out on 5-7 May 2003

The lava dome of the Soufrière Hills volcano continues to grow and is the largest that it has ever been. The dome has a volume of over 200 million cubic metres and the summit is around 1100 metres above sea level, which is 190 metres (about 600 feet) higher than Chances Peak. The dome remains very dynamic with typically hundreds of rockfalls per day, some hundreds of long period earthquakes per week and emissions of hundreds of tonnes of sulphur dioxide gas per day. Over the last 6 months there have been several episodes of dome collapse generating pyroclastic flows that traveled several kilometres. Some collapses of the dome to the north and northwest have fed small pyroclastic flows into Tyre's Ghaut, some of which have traveled as much as 2 km reaching Dyers bridge in the upper parts of the Belham valley. The lower Belham valley remains highly hazardous and vulnerable to dome collapses that exceed volumes of about 3 million cubic metres (1.5% of the current dome volume). Large collapses can develop with little warning and flows to the northwest could take less than 3 minutes to reach the Belham bridge. With the hurricane season approaching the probability of a large dome collapse triggered by intense rainfall will increase. A large collapse of the dome in directions other than north or northwest (e.g. down the Tar River) could result in a significant reduction in risk levels, particularly to the lower Belham valley. All the evidence indicates that the level of hazard is increasing as the dome grows. Hazardous conditions will continue as long as the dome maintains a large volume and remains active.

Montserrat Scientific Advisory Committee

12 May 2003

Appendix 5: Glossary of Terms

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

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.

Intensity: The standard measure of the power of an explosive eruption is the intensity and is defined as the mass flux of material coming out of the volcano.

Lahar: A flow of rock debris, ash and mud that occurs on many volcanoes particularly during eruptions. Large lahars can be very destructive and can be a major cause of death.

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 in an event.

Plume: A buoyant mixture of hot air and volcanic particles that rises above the volcano high into the atmosphere.

Pumice: Pumice is bubbly frozen magma. Fragments of pumice are common on Montserrat and are essentially frothy light rock with a density similar to water (about 1 g/cc).

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.

Tephra: A general term for all fragmented volcanic materials, including blocks of rock, pumice and volcanic ash.

Viscosity: This is measure of how difficult it is for a fluid to flow. The andesite of Montserrat has a viscosity about one million times greater than the fluid lavas at volcanoes like Hawaii.

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 6: 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.