Working on Volcanoes

INTRODUCTION

GNS Science recognises a **hazard** associated with working on volcanoes. GNS Science wishes to **minimise** the potential for death, injury or trauma, whilst enabling safe, cost-effective science to be carried out.

These Health and Safety guidelines have been prepared for GNS Science personnel undertaking field investigations on volcanoes. The aims of these guidelines are to ensure that hazards associated with working on volcanoes are identified, and to set out procedures to minimise the risks to GNS Science staff while engaged in such. These guidelines should be read in conjunction with GNS Science Health and Safety procedures "Field Safety (for field work inside NZ)", Procedure 3.44.

These guidelines are not a substitute for common sense, self reliance, and personal responsibility. There are hazards in the real world, and everyone is vulnerable: some risks must be accepted if GNS Science staff are to undertake field work on volcanoes. These guidelines merely provide an overview to ensure that hazards have been identified and mitigated against such that risks are minimised as far as practicable.

GNS Science will provide employees with adequate personal protective equipment for working in volcanic areas, which may include gas masks, appropriate footwear, hard hats etc. (see GNS Science Policy number 1.33).

RESPONSIBILITIES

These guidelines identify key roles for:

- Section Managers who are responsible for ensuring that field staff are aware of potential hazards and that they are suitably qualified, experienced and equipped.
- Field Leaders who have the final responsibility for the safe and efficient completion of field work, including planning objectives, the selection and chartering of aircraft and other vehicles, ensuring permits are in place, and leading the scientific team.
- Individuals who must abide by the GNS Science policy and procedure and who have ultimate responsibility for their wellbeing.

The Section Manager is responsible for overseeing the activities of GNS Science personnel with regard to health and safety matters. However, the Field Leader takes this responsibility once the party has left the base. GNS Science staff are also responsible for people who have been contracted to work for GNS Science. Usually, this is achieved by asking to see the contractors H&S plan and checking that it meets GNS Science requirements. Personnel from other organisations who may be working jointly in the field are expected to be operating under their own health and safety policies, although the Field Leader should intervene if any unsafe practices are proposed or commenced. Ultimately, individuals are responsible for their own and others' safety.

GNS Science is best able to minimise the risk associated with working on volcanoes by influencing the behaviour and practice of its staff and Field Leaders in particular.

All field intention forms should be lodged at Wairakei, where the site administration staff are responsible for checking field workers out of the field and initialising procedures for SAR if a field party are overdue.

PLANNING

- A field trip intentions form must be prepared and notified to reception.
- There shall be a clearly defined Field Leader. Although the team may consist of groups from different surveillance teams (e.g., ground deformation and soil gas geochemistry), there shall only be one Field Leader who is responsible for communication with the base (especially changes in departure/arrival times and make up of the field team). Any team member can act in response to a life-threatening situation.
- Surveillance field teams must be kept as small as possible to lessen the risk of exposure to hazards. Only essential personnel are to be included in a surveillance team, particularly when the Volcanic Alert Level is at 2 or above.
- When using helicopter or light aircraft, the relevant GNS Science Health and Safety work guidelines for the use of aircraft should be followed.
- Helicopter support is essential if you are working near an active crater at Alert Level 2 or greater. It is not acceptable to allow the helicopter to undertake other work and return for you later.
- The Team Leader should ensure that all party and personal equipment is in good order and includes an appropriate high-visibility garment.
- The Team Leader should ensure that appropriate communications devices are taken in the field, that they are in working order and that each member of the party knows how to operate them. Devices may include cellular phone, satellite phone, mountain radio, or VHF. Satellite phones should be pre-programmed with GNS Science office and Search and Rescue (SAR) numbers.
- The Team Leader should ensure that a communications schedule is set and adhered to as per the field intentions form and that any changes are notified to reception as soon as possible.
- Communications equipment should be protected from rain and other nasty environments.
- The Team Leader should ensure that all parties have a First Aid kit with wasp kits and burns kit, and an adequate supply of clean water for cooling burns.
- Sufficient food should be taken for the trip plus a margin for possible delays.
- Before working on a frequently active volcano, Field Party Leaders should check current activity with the Volcano Duty Officer. If no recent anomalous monitoring data[1] have been collected and seismicity is low in the morning prior to a field visit, the volcano can be deemed in a state of quiescence when the field team departs. However, Field Party Leaders must recognise that low seismicity does not preclude the risk of a sudden so-called “blue sky” eruption with no warning.

[1] Anomalous monitoring data refers primarily to increased seismic activity, but may also include observations or other recently collected data.

HAZARDS AND RISK REDUCTION

There are many hazards associated with active volcanoes. Many of these are common to all volcanoes, although some are specific to certain areas. The hazards can be divided into non-eruptive and eruptive impacts.

Non-eruptive hazards

Fumarolic gas poisoning

Two levels of poisoning are possible: short term and long term. In the short term, people who are susceptible to respiratory problems, such as asthmatics, may experience difficulties when in areas of high gas concentration. Short term effects can also include headaches and increased coughing for up to two days during and after a field visit. Long term respiratory problems may result from repeated exposure to gases on field visits.

Risk reduction:
Several methods are available to reduce the risk due to fumarolic gas poisoning. The main preventative method is to use a gas mask. Four different types of gas masks are available (in order of increasing protection): acid gas filter masks; full face acid gas filter masks; pumped/hooded acid gas filter systems; and bottled air full-face systems. Risk is also reduced by having only two personnel sampling a fumarole. Gas detectors (dedicated O_2 and CO_2 level monitors) should be carried by staff so that an alert is given when high gas concentrations are encountered. If a detector sounds an alert indicating high carbon dioxide, staff in the immediate vicinity should move away from the area as quickly and safely as possible. Low lying areas should also be avoided as ponding of CO_2 can occur in the depressions (see below).

Burns from fumaroles

Burns from fumaroles can include both heat (from hot gases) and chemical burns (from acidic or alkalic fluids).

Risk reduction:
Risk from burns is reduced by wearing appropriate protective clothing. This might include overalls, gumboots, eye protection, gloves and gas masks (as above). Burns kits, first aid kits and water are also to be carried in case of an accident.

Gas ponding in low areas

The main impact from gas ponding in low areas, for example around crater lakes, is rapid suffocation due to exclusion of oxygen from the atmosphere. There are many examples worldwide where ponding has resulted in fatalities in volcanic areas. These include four deaths at Mammoth, USA (1998, 2006) due to high CO_2 concentrations, and the deaths of three soldiers at Hakkoda, Japan (1997) by inhalation of gas.

Risk reduction:
The key strategy for reducing the risk of suffocation is to recognise the hazard by observing topography, and wind strength and direction. Thus topographically low areas e.g. deep enclosed craters should be avoided. Gas detectors should be carried by staff so that an alert is given when high gas concentrations are encountered. If a detector sounds an alert indicating high carbon dioxide, staff in the immediate vicinity should move away from the area as quickly and safely as possible.

Hot unstable ground

Most volcanic and geothermal areas have unstable ground which may be hot beneath the surface. More susceptible areas include fumarolic fields, especially if there is a high water table or if there has been recent rainfall. Unstable areas may be susceptible to collapse due to subsurface alteration. Recent pyroclastic flow deposits may also be very unstable.

Risk reduction:
There should always be at least one experienced person per party. Pre-existing tracks are more likely to be stable, so these should be used where possible, and dangerous ground should be avoided. A pole or spade should be carried to test ground ahead, and protective footwear should be worn (gumboots or gaiters without open tops). Other protective clothing such as overalls should help to reduce any injury, and the field party should carry water, burns kits, and general first aid kits.

Burns from hot water and mud in streams and in crater lakes

The impacts and consequent risk reduction strategy are similar to encountering hot unstable ground. It should be noted that sudden outpourings of hot mud and water from mud pots can occur, and so locations downstream from mud pots should be avoided.

Landslide

Landslides can produce two main impacts: direct hit on personnel or production of waves at water's edge triggered by a landslide into a crater lake. Larger landslides can lead to lahars in specific catchments caused by lake water overtopping a crater lake rim. There is often little immediate indication of an imminent landslide, although cracks in a crater wall and slow creep of the wall can be observed. If acceleration is noted in either the crack width or creep of the wall, then the landslide hazard would increase.

Risk reduction:
As heavy rainfall can trigger landslides, it is advisable not to visit a susceptible area during or immediately after intense rain. Equally, if there is intense earthquake activity in the area, slopes can become unstable and susceptible areas should be avoided.

Non-eruptive lahar

There are two mechanisms for generating a lahar during non-eruptive periods. Firstly, a landslide or icefall can generate a lahar if they occur into a crater lake. This can cause overtopping of the lake and the onset of the lahar. Secondly, a lahar might be generated by dam break of a crater lake. Piping failure is a possible mechanism for the onset of the dam break. Non-eruptive lahars are most likely to occur in specific catchments, and the likelihood of a dam break lahar will increase if the lake level is high (e.g. at White Island).

Risk reduction:
For landslide-generated lahars, the precautions are similar to landslides i.e., reduce visits to susceptible areas during and after heavy rain or during intense seismic activity. For dam break lahars, as the catchments for the lahar pathway are reasonably well-known, the main risk reduction strategy is to minimise the time spent in those catchments. In the case of piping failures, an increase in seepage downstream of the crater lake might indicate the onset of piping. During periods of increased lahar hazard e.g., when the crater lake is at overflow, drainage channels directly below the overflow should be avoided.

Eruptive hazards

The hazards associated with eruptive periods are inevitably more numerous and more dangerous. All the non-eruptive hazards are still present, so the number of injurious phenomena is vastly increased. In this section, the individual hazards are described in turn. One key issue is the time delay after the last eruption that is needed before an eruptive episode can be declared over, i.e., so that the eruptive hazards are thought to be much reduced. This is likely to be of the order of a one to several months, depending on the level of activity, although on all volcanoes, sudden "blue sky" explosions can occur with little or no warning.

Ballistics

Ballistic projectiles from explosive eruptions (phreatic or magmatic) usually impact within 3 km of the vent area. The main impact from ballistics is head injury. Impact of a lithic rock of greater than ca. 10 cm on a skull (Baxter, pers. comm.) can result in a serious head injury. Other serious impacts are a result of hot rock giving burns or ballistics breaking other bones such as legs, arms and back.

Risk reduction:
For small ballistics, wearing a hard hat reduces injury. Wearing protective overalls can also reduce impact from hot rocks. If in the field when an explosion occurs, two courses of action can limit the impact of ballistics. The first is to find shelter behind large boulders or buildings. The second is to watch where the ballistics are falling and move out of the way of the larger impacts.

Blast

A blast is a horizontally directed explosion. It will often contain lava fragments and has many of the characteristics of an energetic pyroclastic surge. Deaths occur by asphyxiation, burns, burial, and impact by clasts. The eruption of Mt St Helens on 18 May 1980 was characterised by a lateral blast following a debris avalanche of the volcano flank. Blasts typically move at speeds of several hundred meters per second. A steam blast will contain only steam and no clasts, and injury is most likely to be due to burns.

Risk reduction:
There is little mitigation against this phenomenon, besides not being present when one occurs. There is some evidence that if someone is on the edge of a blast zone and is wearing a heat protective suit, then survival is possible. Also, if it is possible to find shelter in a solid building, this can give some protection.

Ash fall

Ash fall can vary from a light covering to intensely dark clouds. Even small events can produce thick ash clouds which can disorientate people. Breathing ash in small amounts can exacerbate respiratory conditions such as asthma, and it is possible that repeated exposure to ash can lead to long term chronic silicosis. Ash can also be an eye irritant, especially if there are acidic species adsorbed onto the surface of the ash. At some volcanoes, there have been deaths related to suffocation during long (hours) ash falls; some fatalities are also caused by falls from roofs whilst cleaning ash. Ash in the atmosphere is a hazard to aircraft and it is advisable that aircraft do not fly in fine ash for prolonged periods or in thick ash at all. The location of ash fall is determined largely by the height of the volcanic plume and wind direction.

Risk reduction:
The main risk reduction measure is to wear a respirator. A full face mask will also prevent contact of ash in eyes. During darkness induced by an ashfall, it is better to stay in a single location and wait for the ash to clear to prevent movement over hazardous ground during poor visibility.

Collapse of crater rims

During an eruption, new craters can form or existing craters can be expanded by collapse. Often fumarolic areas will develop into small craters and then into larger craters during an eruptive period. This might also occur in non-eruptive periods. Crater formation and modification can occur suddenly over a few minutes or progressively over a few days.

Risk reduction:
The key process is to stay well clear of the edges of craters. If sampling necessitates going close to craters, then ropes should be used. Also, there has to be awareness by field personnel that toxic gas levels are likely to be higher in craters and if a person falls into a crater, they (and potential rescuers) might be exposed to dangerous levels of gas.

Pyroclastic density currents

Pyroclastic density current (PDC) is the general term for a gravity current which contains volcanic clasts, hot gases and entrained air. PDCs include dense pyroclastic flows, dilute pyroclastic surges and volcanic blasts (see above). They are formed by gravitational collapse of a lava dome, fountain collapse of an explosive eruption column or by lateral explosion. They can move fast (several hundred meters per second) and can be hot (several hundred degrees centigrade). Pyroclastic flows tend to be valley confined, whereas surges are more energetic and can travel over topographic obstacles.

PDCs have accounted for the most deaths from volcanoes in the last hundred years (Witham, 2005). Deaths occur by asphyxiation, burns, burial, and impact by clasts.

Risk reduction:
As with blasts, there is little mitigation against this phenomenon, besides not being present when one occurs. There is some evidence that if someone is on the edge of a PDC zone and is wearing a heat protective suit, then survival is possible. Also, if it is possible to find shelter in a solid building, this can give some protection.

Increased environmental gas and acid rain

During an eruptive period, there are likely to be greater amounts of magmatic gases emitted into the atmosphere. This can lead to higher levels of toxic gas at ground level. Higher concentrations in the atmosphere can also lead to the formation of acid rain during normal orographic precipitation or through precipitation from the volcanic plume.

For increased gas levels, there would be a higher risk for gas ponding in topographically low areas, and for respiratory problems from breathing in noxious gases. For acid rain, the effects would be non-catastrophic, but unpleasant with burning on skin and irritation of eyes.

Risk reduction:
Gas ponding hazards can be avoided by taking the same precautions as above i.e. by avoiding low areas, carrying a gas detection device, and wearing a gas mask, preferably with

pumped air. Acid rain hazards can be mitigated against by wearing overalls, goggles, and gloves.

Lahar caused by eruption through a crater lake

Lahars can be caused by an eruption leading to overflow and/or an explosion emptying the crater lake. This could lead to lahars in more than one catchment. A small eruption would probably only affect the immediate vent area and possibly one catchment; a larger eruption would result in lahars in multiple catchments.

Risk reduction:
For eruption-generated lahars, the main risk reduction strategy is to minimise the time spent in at-risk catchments. For a large eruption, the only solution is to get to higher ground as fast as possible after onset of the eruption, although there would likely be other eruption effects (ash fall, ballistics) which might mean movement would be difficult.

Lava flows

Lava flows represent a relatively low level hazard since they are generally slow moving, and flow paths are relatively predictable. However, for thick a'a lava flows, large hot blocks can become unstable from the leading edge of a flow, and cause severe injury. If travelling over wet ground, small phreatic eruptions can also be produced as water flashes to steam.

Risk reduction:
As lava flows tend to be slow moving and follow topographically low pathways, the main mitigation is to stay away from valley bottoms, if flows are likely. If working in the vicinity of lava flows, the pathway should be regularly checked since breakouts can happen quickly and isolate observers in kipukas.

QUANTITATIVE RISK ASSESSMENT

General

Quantitative risk assessments should be undertaken to determine the level of volcanic risk (on an annualised basis) to which field personnel are subjected whilst working on New Zealand's volcanoes. It should also be recognised that some staff may work on overseas volcanoes e.g., on Vanuatu, and exposure time in those areas must also be taken into account. On most occasions the risk is associated with quiescent volcanoes i.e., those that show no signs of significant unrest or have not had a recent eruption, but can still have a small chance of erupting suddenly without warning (for definitions of significant unrest and eruption periods see Appendices 1 and 2). If the volcano is deemed to be either in a state of significant unrest or in an eruptive period, then the Volcanology Section Manager should be informed before work is undertaken, as a different risk calculation is required.

As identified above, there are two main areas of risk: (a) non-eruptive hazards and (b) eruptive hazards. The risks for non-eruptive hazards are not calculated as the risk does not vary significantly, and are generally either low impact and/or low probability events.

The calculations for risk due to eruptions need to be reviewed at least on an annual basis to check whether new information is available to change the assessment.

Risk calculation methodologies

Risk during quiescence (Alert Level 0 or 1)

It is assumed here that the risk associated with working on a quiescent "re-awakening" volcano is negligible, since there should be significant indicators of unrest prior to an eruption. Hence the risk from eruptions whilst working on a quiescent "re-awakening" volcano is not addressed in these guidelines.

The main eruption risk on quiescent frequently active volcanoes is from an eruption that has no recognisable precursors (so called "blue sky eruptions").

Before working on a quiescent frequently active volcano (i.e., Ruapehu, White Island, Tongariro, Ngauruhoe, Raoul Island), Field Party Leaders should check current activity with the Volcano Duty Officer before their team goes into the field. If no recent anomalous monitoring data have been collected and seismicity is low in the morning prior to a field visit, the volcano can be deemed in a state of quiescence when the field team departs.

Risk calculations during quiescence on a frequently active volcano are based on eruptive history. An analysis of historic activity at each frequently active volcano (White Island, Ruapehu, Ngauruhoe, Tongariro, Raoul Island) shows how many times a life-threatening eruption has occurred at each volcano (a) with less than 6 hours warning (6 hours being the length of a normal field day), (b) outside an eruptive period **and** (c) outside a period of significant unrest[2]. These data are shown in Table 1. This assumes there is no real-time warning of an eruption. At Ruapehu, EDS should provide notification of an eruption that can warn staff working at a distance from the vent, however, most times, the field party would be the first people to be aware of an eruption.

Table 1. Return periods for potentially life threatening eruptions with no recognised precursory activity at New Zealand's frequently active volcanoes. Note: these numbers are the best available at the time of writing. With more detailed research, the risk will be better defined. Dates of each eruption in the table are shown in Appendix 3.

	Number of years	Maximum and minimum number of life-threatening eruptions with no precursory activity[3]	Maximum and minimum number of life –threatening eruptions **per year** with no precursory activity
White Island	50	2-3	0.04-0.06
Ngauruhoe	50	0	0
Ruapehu	50	3-7	0.06-0.14
Tongariro	153	0	0
Raoul Island	200	0-1	0.005

Note that the risks would be primarily associated with sudden onset explosive eruptions producing ballistics and surges within 3 km of the vent, and so these risks only apply to workers within this distance. Risks would be much lower at greater distances. It is considered that larger eruptions affecting greater distances from a vent would have noticeable precursory activity.

[2] The definition of unrest will be different for each volcano.
[3] Ngauruhoe appears to mostly have precursory activity before eruptions, usually vigorous steaming from the crater and fumaroles. The record of eruptions at Tongariro is not good enough to make a judgment on whether there was precursory activity. Given that the time since the last eruption is long, one would probably expect there to be significant unrest before an eruption.

Calculating risk during volcanic unrest

Volcanic unrest can be defined as anomalous seismicity, geodetic strain, fumarolic activity, gas emissions or other changes above normal background levels, which may or may not lead to an eruption.

Using global statistics (Newhall and Hoblitt, 2002), once a period of significant unrest is initiated, the likelihood of an eruption within one year is between 10 and 50%. This assumes that the unrest is attributed to intrusion of new magma. Detailed knowledge of the relationship between unrest indicators and probability of eruptions at specific volcanoes can better inform risk at individual volcanoes but, since this has yet to be rigorously applied at individual volcanoes in New Zealand, the global statistics are currently the best starting estimate of risk that are available.

As noted previously the parameters which define significant unrest at each volcano are likely to be quite different. Since these parameters have yet to be discussed by the volcanology team, the decision about whether significant unrest is present is currently made by consensus in a surveillance meeting. The surveillance group should discuss the activity and decide whether there is a change in risk (i.e., whether an eruption is more likely) using knowledge of the volcanic system and expert judgment.

Any fieldwork during a period of significant unrest should be approved by the Volcanology Section Manager.

Calculating risk during an eruptive period

Following an initial eruption, the probability of further eruptions could be higher or lower, depending on the volcano, the style of the eruption and the magnitude of the eruption. Before fieldwork is initiated, a full discussion with the volcanology team is required to assess the likelihood of further eruption based on monitoring data and comparison with historical activity at that volcano or other similar volcanoes worldwide[4]. If there is any doubt, then fieldwork within 3 km of the vent should be suspended for at least 24 hours.

Any fieldwork during an eruptive period should be approved by the Volcanology Section Manager.

Tolerable risk

The risk for an individual per hour spent in the hazardous zone can be calculated by dividing the annualised risk by 365 x 24. Multiplying this hourly risk by the number of hours spent in the hazardous zone, gives a total risk for that period of fieldwork.

As the total exposure of any individual is the sum of all the risks that are undertaken through fieldwork on volcanoes, all risks need to be summed. A log should be kept by the Volcanology Section Manager for individuals of their time spent in hazardous areas. Using 0.001 as a maximum tolerable risk, this limit should not be exceeded in any one year for a single person's total risk.

As an indication of allowable time, using 0.001 as the limit, the total number of hours per year that can be spent in hazardous areas can be calculated by dividing 0.001 by the annualised

[4] It may be possible to pre-define a series of possible scenarios to define the risk after an eruption for individual volcanoes, but given that each eruption is different, these prescriptive scenarios may not be relevant. More research is needed to determine whether pre-defined scenarios would be useful and subsequently to calculate probabilities for them.

risk per hour or work. Table 2 gives the hours allowed per volcano during quiescence.

Table 2. Allowable hours per volcano during quiescent periods (based on a tolerable risk of 0.001).

	Annualised risk of an eruption during quiescence with no precursory activity.	Hourly risk of an eruption during quiescence with no precursory activity.	Allowable hours per year	Number of field days (@6 hours per day)
White Island	0.04-0.06	4.6-6.8 $x10^{-6}$	147-220	24-36
Ngauruhoe	0	n/a	n/a	n/a
Ruapehu	0.06-0.14	6.8-16 $x10^{-6}$	62-147	10-24
Tongariro	0	n/a	n/a	n/a
Raoul Island	0.005	0-5.7 $x10^{-7}$	1750	291

TRAINING REQUIREMENTS

All GNS Science field staff are required to have (depending on the nature of the field work):

- Current certificates in Comprehensive First Aid - Field
- Current medical certificate
- 4WD training and experience
- Training in operations around aircraft, particularly helicopters
- Training or relevant experience in Mountain Skills if working above the snowline.

In addition, GNS Science Field Party Leaders should ensure that they either know the experience and capabilities of their party personally, or check carefully the credentials, experience and field capabilities of whom they are recruiting into the field. Training of new or inexperienced personnel should be undertaken by Field Party Leaders through mentoring in the field e.g., indicating how to avoid or detect unstable ground.

INCIDENT AND INJURY RESPONSE PROCEDURES

Any injuries or incidents are to be reported to the Field Leader if s/he is not already aware of them. In the event of an injury, the first priority is to ensure the wellbeing of the injured person(s), and if necessary they should be evacuated. Any physical injuries that occur will be treated using appropriate first aid procedures; it is GNS Science policy that all GNS Science field staff have up-to-date field first aid training. First aid kits are always carried, as well as communication devices (satellite phone, cell phone or mountain radio). If the accident is in a remote location, SAR (police) procedures may be necessary and these can be activated by cell phone, radio or satellite phone. Alternatively, an EPIRB should be triggered if the emergency is serious.

Overdue procedures

Should part of a field party be overdue, the Field Leader should take appropriate action such as calling site administration to inform them of the situation. Should the entire field party be overdue, the site administration staff should initiate action. Such action should include:

- Checking with named staff on field intentions form to verify the field party has not yet returned.

- Advising the Site Manager and appropriate Section Manager of the situation, including what steps have already been taken.
- Visiting the last known location of the missing party, if feasible.
- Advising SAR if it is believed an accident may have occurred or if a search is required.
- Co-operating with the Police and SAR if a search operation is required.

Follow-up procedures after an incident

Any accident or near miss incident should be reported to the Health and Safety Coordinator and Section Managers, who will deal with these in accord with GNS Science Health and Safety procedures. In the event of a serious accident requiring prompt evacuation of the injured person to a medical treatment facility, some or all of the remaining field party may be withdrawn. The accident site will be left undisturbed except for any actions that are needed to treat the injured person(s). Family members will be notified of the circumstances following a serious accident. All staff in HR, Section Managers and General Managers have access to personal contact information.

REFERENCES

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Witham, C. S. (2005) Volcanic disasters and incidents: A new database. Journal of Volcanology and Geothermal Research 148, 191–233, ISSN 0377-0273.

APPENDIX 1 - DEFINITION OF AN ERUPTIVE PERIOD

An eruptive period can be defined as a period of time including one or more eruptions when the volcano is in an elevated state of activity. Following the end of an eruption, there should be a period of at least one month that is defined as being within the eruption period and during which time work in the vicinity of the vent is deemed to be higher risk.

APPENDIX 2 - DEFINITION OF SIGNIFICANT UNREST

Significant unrest can be defined as anomalous seismicity, geodetic strain, fumarolic activity, gas emissions or other change above normal background levels, potentially, but not necessarily, precursory to an eruption. Eruption precursors might be different for each eruption at each volcano, but some generalities can be discussed that would mean a volcano is behaving outside of its normal constraints.

APPENDIX 3 - POTENTIALLY LIFE-THREATENING HISTORIC ERUPTIONS, OUTSIDE AN ERUPTIVE PERIOD, WITH NO RECOGNISED PRECURSORY ACTIVITY FOR THE FREQUENTLY ACTIVE VOLCANOES

Dates in bold are most likely “blue sky” eruptions; dates in normal type face might be considered to have precursory activity or there is no information on precursory activity. With hindsight, the Raoul eruption in 2006 did have precursory activity, although it wasn’t recognised as such at the time.

For White Island and Ruapehu the last 50 years of data are used, since it is considered that the record will be more complete in this time interval. For Raoul, the entire historic period is used, since it is reasonably certain that the only eruptions were in 1814, 1870, 1886, 1964 and 2006, with only 2006 being with no recognised precursors.

	Number of years	Dates of potentially life-threatening eruptions with no precursory activity
White Island	50	15 Dec 1962; **13 Nov 1966; ?30 Jun 1970;**
Ruapehu	50	22 Jun 1969, 8 May 1971; **24 Apr 1975**; 2 Nov 1977; **?22 Mar 1988**; 18 Sep 1995; **25 Sep 2007**
Raoul Island	200	**17 Mar 2006**