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# Review of self-isolation and restoration risk assessment models

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# Review of self-isolation and restoration risk assessment models

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The gas distribution network operators (GDNs) must prepare emergency plans to respond to a widespread or prolonged loss of gas supply incident occurring on their part of the network. These plans are a requirement of the Gas Safety (Management) Regulations 1996 (GSMR) and form part of the safety case arrangements made by the GDNs.

This report provides an independent review of two risk assessment models that will be used in conjunction with the GDNs' gas supply emergency response plans. These models predict the anticipated number of fatalities from gas incidents during isolation and restoration of the gas supply and the anticipated number of fatalities from the effects of low indoor temperature that might be encountered during a gas supply emergency. The outputs of these models will be used by the GDNs to determine whether the gas supply to each affected property should be isolated and later restored by GDN-appointed personnel or by the gas consumer themselves.

This review covers the assumptions made in the models, the data used, and the techniques used to manipulate the data, and concludes that the overall approach adopted in the risk assessment models is appropriate. Some modifications to the models are recommended, but it is not anticipated that these modifications would affect the conclusions reached using the model, in the majority of cases.

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**HSE Books**

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# KEY MESSAGES

GL Noble Denton has developed two risk assessment models for use in conjunction with the gas distribution network operators' (DNOs) winter contingency plans for responding to an exceptionally large and prolonged loss of gas supply incident. These models predict the anticipated number of fatalities from gas incidents during isolation and restoration of the gas supply and the anticipated number of fatalities from the effects of low indoor temperature during a gas supply outage. The outputs of these models will be used to determine whether the gas supply to each affected property must be isolated and later restored by an engineer, or whether it is appropriate for the customer to perform these procedures his or herself.

It is the responsibility of the Health and Safety Executive (HSE) to assess and validate the contingency plans for possible acceptance into the DNOs' safety case demonstration material. To aid this process, HSE asked the Health and Safety Laboratory (HSL) to carry out an independent review of the models developed by GL Noble Denton. HSL has reviewed the assumptions made in the models, the data used, and the techniques used to manipulate the data. The review has concentrated on the inputs shown by GL Noble Denton's sensitivity studies to be the most important.

HSL has concluded that the overall approach adopted in the two risk assessment models is appropriate. The models make use of event tree analysis: a comprehensive list of scenarios has been considered and in general, the input data have been manipulated correctly in the event tree. However, HSL has some concerns about the suitability of some of the data sources used.

As a result of its review, HSL recommends that certain corrections and modifications be made to GL Noble Denton's risk assessment models. In particular, HSL recommends that the data used to derive some of the key assumptions be reviewed, and that literature searches be carried out to identify other possible data sources. Implementation of these recommendations would reduce the uncertainty associated with certain model inputs and allow greater confidence to be placed in the data on which the models are based. This would strengthen the case for incorporating the proposed contingency plans into the DNOs' safety case demonstration material.

For the majority of the test scenarios modelled using the graphs derived by GL Noble Denton, the use of customer self-isolation and restoration is strongly favoured. Specifically, the model predicts that the use of customer self-isolation and restoration will reduce the duration of the supply loss sufficiently that the increase in the number of fatalities arising during the restoration procedure will be outweighed by the decrease in the number of fatalities caused by exposure to low indoor temperatures.

If all the changes to the models recommended by HSL were implemented, it is probable that this would lead to an increase in the predicted risk of a fatality from low indoor temperatures and a decrease in the predicted risk of a fatality from customer self-isolation and restoration. Thus, for the majority of the test cases, the conclusions reached using the model would not change, and for most of the scenarios, the case for using customer self-isolation and restoration would become even stronger.

# EXECUTIVE SUMMARY

The gas distribution network operators (DNOs) are currently reviewing their winter contingency plans for responding to an exceptionally large and prolonged loss of gas supply incident. These plans are used to determine whether the gas supply to each affected property must be isolated and later restored by an engineer, or whether it is appropriate for the customer to perform these procedures his or herself. Scotia Gas Network (SGN) is coordinating this review on behalf of all the DNOs.

At present, the contingency plans and associated emergency procedures do not form part of the DNOs' safety cases. However, these procedures could be incorporated into the safety case demonstration material if the DNOs can demonstrate that they comply with the Gas Safety (Management) Regulations (GSMR) and the Gas Safety (Installation and Use) Regulations (GSIUR). To achieve this, the DNOs will need to demonstrate that the procedures are based on a thorough assessment of the relative magnitudes of the risks to the public from self-restoration and from the prevailing weather conditions. This risk assessment should also include 'trigger levels' or a decision-making tool for determining whether the use of customer self-isolation and restoration is appropriate. To fulfil these requirements, SGN commissioned GL Noble Denton to develop a methodology for predicting the anticipated number of fatalities from gas incidents during isolation and restoration and the anticipated number of fatalities from the effects of low indoor temperature during a gas supply outage.

It is the responsibility of the Health and Safety Executive (HSE) to assess and validate the contingency plans for possible acceptance into the DNOs' safety case demonstration material. To aid this process, HSE asked the Health and Safety Laboratory (HSL) to carry out an independent review of the risk assessment models developed by GL Noble Denton.

## OBJECTIVES

The objective of this work was to provide HSE with an independent technical review of the risk assessment models developed for the DNOs by GL Noble Denton, and to determine whether these models provide a suitable basis for deciding whether customer self-isolation and restoration is an appropriate option. The review included:

- An analysis of the risk assessment methods used; and
- A discussion of the assumptions made and data sources used.

## MAIN FINDINGS

GL Noble Denton has developed two separate risk assessment models for use in conjunction with the DNOs' winter contingency plans. The first, referred to here as the 'Self-Isolation and Restoration model', predicts the number of fatalities caused by gas incidents that could occur during isolation and restoration. The output of this model is a graph on which the number of fatalities is plotted as a function of the number of properties where a gas supply failure has occurred. Separate traces are plotted for the scenario in which customer self-isolation and restoration occurs and that in which a qualified person carries out the isolation and restoration.

The second model, known as the 'Cold Weather model', predicts the number of fatalities that could occur as a result of the low indoor temperatures experienced during a gas supply outage. The output of the model is a graph that relates the predicted number of additional fatalities due to the temperature drop to the duration of the gas supply loss, for a series of outdoor temperature bands.

HSL has concluded that the overall approach adopted in the Self-Isolation and Restoration model is appropriate. Self-isolation and restoration is a complex process to model and the overall event tree has been logically split up into smaller parts, which are considered on separate worksheets. Two possible causes of a fatality have been considered in the model, namely i) flashback following delayed ignition of an appliance during restoration, and ii) a gas explosion.

The number of fatalities predicted by the Self-Isolation and Restoration model is dominated by fatalities from flashback, so the risk of a fatality from a fall is a key input. HSL has assessed the raw data used in the derivation of this input and has concluded that there is a large uncertainty associated with the chosen input value. It is probable that the value currently used in the model is an overestimate of the true value.

The number of fatalities that is predicted to occur as a result of gas explosions is negligible in comparison to the predicted number of fatalities from flashback. Several small errors relating to modelling of gas explosions were identified during the course of the review, but none will have a significant effect on the model output.

In general, the input data have been manipulated correctly in the event tree and Boolean logic has been used where appropriate. However, an error has been identified in the way in which the risks of fatality from different scenarios have been combined. For the currently used input values, the effect of this error on the model output is small.

HSL has concluded that appropriate modelling techniques have also been used in the Cold Weather model. However, HSL has some concerns about the suitability of some of the data sources used to determine the dependence of the number of Excess Winter Deaths on temperature and to determine the number of additional Excess Winter Deaths caused by the loss of the gas supply. It is important that appropriate values are chosen for these inputs, because sensitivity studies carried out by GL Noble Denton indicate that these are the two inputs that have the most significant impact on the model output.

Neither model accounts for the age or vulnerability of the affected customers. The majority of Excess Winter Deaths occur among those aged 75 or over, but it is also known that the elderly are the population group most at risk of suffering a fatal fall during the restoration procedure. It would be of interest to know whether the model outputs would favour the use of customer self-isolation and restoration if the input values were tailored to describe elderly customers.

## KEY RECOMMENDATIONS

### Self-isolation and restoration model

- The DNOs and HSE may wish to consider whether the risk of a fatality occurring during the isolation procedure should be calculated within the model.

- The value chosen for the risk of a fatality from a fall in the home has a significant effect on the predicted number of fatalities. There is a large uncertainty associated with the value that has been derived for this input. HSL recognises that the data required to reduce the uncertainty are unlikely to be readily available. However, users of the model should be made aware that the value chosen for this input is a cautious estimate with a large associated uncertainty.

- The error in the methodology used to combine the risks of fatality from different scenarios should be corrected.

- The output of the self-isolation and restoration model is a graph on which the number of fatalities is plotted as a function of the number of properties where a gas supply failure has occurred. HSL recommends that the graph be modified to show the number of fatalities per 1000 affected properties as a function of the duration of the supply loss. This approach has the twin advantages of providing consistency between the outputs of the two models and avoiding the need to make assumptions about the duration of the supply loss.

### Cold weather model

- In the Cold Weather model, the number of Excess Winter Deaths has been linked to the average winter temperature. However, there is a stronger relationship between the *daily* outside temperature and the number of Excess Winter Deaths and HSL recommends that the model be modified to reflect this.

- GL Noble Denton has assumed that the temperature in a house affected by a gas supply failure is well represented by the average temperature in the 25% coldest of homes. However, the temperature in a property with no gas supply is likely to fall to a value much lower than this average value. Since mortality rates increase as the indoor temperature decreases, this may lead to an underestimate in the number of additional Excess Winter Deaths caused by the loss of gas supply. Therefore, HSL recommends that a literature review be carried out, to determine whether sufficient information exists to derive the number of additional Excess Winter Deaths that occur in (for example) the 10% coldest of homes.

- The output of the Cold Weather model is a graph that relates the predicted number of additional fatalities due to the temperature drop to the duration of the gas supply loss, for a series of outdoor temperature bands. In the current version of the model, all temperatures below 5 ºC are represented by a temperature of 0 ºC. This is likely to lead to an underestimate in the number of additional deaths that will occur in sub-zero conditions. Therefore, HSL recommends that temperature bands should not be used and that the model should be modified to calculate the predicted number of fatalities at regular outdoor temperature intervals.

### Implications of the recommendations

In the event of a loss of gas supply incident, the DNO will determine the number of households affected and the number of engineers available to respond to the incident. From this information, the expected duration of the supply loss can be predicted for the scenario in which all isolation and restoration procedures are carried out by engineers, and the scenario in which customer self-isolation and restoration is used. The graphs derived by GL Noble Denton will then be used to predict the anticipated number of fatalities from gas incidents and the anticipated number of fatalities from the effect of the weather, for both scenarios, and the results will be compared. For the majority of the test scenarios modelled by SGN using the graphs derived by GL Noble Denton, the use of customer self-isolation and restoration is strongly favoured.

If all the changes to the models recommended by HSL were implemented, it is probable that this would lead to an increase in the predicted risk of a fatality from low indoor temperatures and a decrease in the predicted risk of a fatality from customer self-isolation and restoration. Thus, for the majority of the test cases chosen by SGN, the conclusions reached using the model would not change, and for most of the scenarios, the case for using customer self-isolation and restoration would become even stronger.

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# 1. INTRODUCTION

The gas distribution network operators (DNOs) are currently reviewing their winter contingency plans for responding to an exceptionally large and prolonged loss of gas supply incident. These plans are used to determine whether the gas supply to each affected property must be isolated and later restored by an engineer, or whether it is appropriate for the customer to perform these procedures his or herself. Scotia Gas Network (SGN) is coordinating this review on behalf of all the DNOs.

At present, the contingency plans and associated emergency procedures do not form part of the DNOs' safety cases. However, these procedures could be incorporated into the safety case demonstration material if the DNOs can demonstrate that they comply with the Gas Safety (Management) Regulations (GSMR) and the Gas Safety (Installation and Use) Regulations (GSIUR). To achieve this, the DNOs will need to demonstrate that the procedures are based on a thorough assessment of the relative magnitudes of the risks to the public from self-restoration and from the prevailing weather conditions. This risk assessment should also include 'trigger levels' or a decision-making tool for determining whether the use of customer self-isolation and restoration is appropriate. To fulfil these requirements, SGN commissioned GL Noble Denton to develop a methodology for predicting the anticipated number of fatalities from gas incidents during isolation and restoration and the anticipated number of fatalities from the effects of low indoor temperature during a gas supply outage.

It is the responsibility of the Health and Safety Executive (HSE) to assess and validate the contingency plans for possible acceptance into the DNOs' safety case demonstration material. To aid this process, HSE asked the Health and Safety Laboratory (HSL) to carry out an independent review of the risk assessment models developed by GL Noble Denton.

## 1.1 BACKGROUND

In the event of a gas supply outage, the gas supply at each affected property must be isolated by closing the Emergency Control Valve (ECV). When the gas supply is reinstated at the end of the incident, the supply to each property must be restored by reopening the ECV and relighting all gas appliances. If a large number of properties are affected by the outage, it will take a significant amount of time for engineers to visit each affected property and perform these procedures, and this could delay the reinstatement of the gas supply. Therefore, in their contingency plans for responding to such incidents [1, 2], the DNOs have considered the possibility that these procedures could be performed by the customer his or herself (a scenario known as 'customer self-isolation and restoration'). Leaflets would be provided to the affected households, instructing customers on how to carry out the procedures. This would allow the gas engineers to focus on visiting the homes of those who are unable to carry out the isolation and restoration for themselves, such as the elderly or disabled. The use of customer self-isolation and restoration has the potential to significantly reduce the duration of the gas supply outage, which in turn will reduce the number of fatalities caused by loss of heating and the resulting low temperatures within the home. On the other hand, the probability that a fatality will occur as a result of a gas incident during isolation or restoration is higher if unqualified people carry out these procedures. Weighing up the relative importance of these factors is a fundamental part of the contingency plan.

In previous years, the DNOs used simple tools to decide whether customer self-isolation and restoration should be considered, such as a matrix on which the forecast duration of the incident was compared to the forecast average daily ambient temperature [1]. However, a more thorough assessment of the risks is required to comply with GSMR and GSIUR. Therefore, SGN (acting on behalf of all the DNOs) commissioned GL Noble Denton to carry out a detailed analysis of the relevant issues, and, if feasible, to develop a more robust decision-making tool.

To fulfil this request, GL Noble Denton developed two separate risk assessment models. The first, referred to in this report as the 'Self-Isolation and Restoration model', predicts the number of fatalities caused by gas incidents that could occur during isolation and restoration. The output of this model is a graph on which the number of fatalities is plotted as a function of the number of properties where a gas supply failure has occurred. Separate traces are plotted for the scenario in which customer self-isolation and restoration occurs and that in which a qualified person carries out the isolation and restoration.

The second model, known as the 'Cold Weather model', predicts the number of fatalities that could occur as a result of the low indoor temperatures experienced during a gas supply outage. The output of the model is a graph that relates the predicted number of additional fatalities due to the temperature drop to the duration of the gas supply loss, for a series of outdoor temperature bands.

A draft winter contingency plan incorporating the outputs of these models has been produced [2]. In the event of a loss of gas supply incident, the DNO will determine the number of households affected and the number of engineers available to respond to the incident. From this information, the expected duration of the supply loss can be predicted for the scenario in which all isolation and restoration procedures are carried out by engineers, and for the scenario in which customer self-isolation and restoration is used. The graphs derived by GL Noble Denton will then be used to predict the anticipated number of fatalities from gas incidents and the anticipated number of fatalities from the effect of the weather, for both scenarios. The results will be compared to determine whether customer self-isolation and restoration is an appropriate approach.

HSE asked HSL to carry out an independent review of GL Noble Denton's work and to provide an overall view on whether the risk assessment models are robust and suited to purpose. To facilitate this review, SGN and GL Noble Denton provided HSL with all the relevant documentation, including GL Noble Denton's Phase 1 feasibility report [3], the Phase 2 report describing the models and related sensitivity studies [4], and a list of the equations that have been implemented in the models [5].

## 1.2 OBJECTIVES OF REVIEW

The objective of this work was to provide HSE with an independent technical review of the risk assessment models developed for the DNOs by GL Noble Denton, and to determine whether these models provide a suitable basis for deciding whether customer self-isolation and restoration is an appropriate option. The review included:

- An analysis of the risk assessment methods used; and
- A discussion of the assumptions made and data sources used.

## 1.3 STRUCTURE OF REPORT

The remainder of this report is structured as follows:

- Section 2 describes and reviews GL Noble Denton's Self-Isolation and Restoration model;
- Section 3 describes and reviews GL Noble Denton's Cold Weather model; and
- Section 4 summarises the overall conclusions and recommendations.

# 2. REVIEW OF SELF-ISOLATION AND RESTORATION MODEL

GL Noble Denton's Self-Isolation and Restoration model predicts the number of fatalities caused by gas incidents that could occur following a domestic gas supply failure. Both the scenario in which the supply is isolated and later restored by the customer, and the scenario in which these procedures are carried out by qualified engineers, are considered. The model has been developed in the form of a spreadsheet and makes use of event tree analysis. It is split into a series of worksheets, each of which models a separate section of the overall event diagram. The structure of the model is shown in Figure 1. This report reviews the assumptions made, the data used, and the way in which data have been manipulated.

Customer self-isolation and restoration is only possible if the supply loss is caused by non-damaging contaminants, such as air, or by low pressure in the system. The Gas Distribution Networks do not consider customer self-isolation and restoration to be an appropriate option when damaging contaminants such as water or dust are present, or when the supply loss is caused by over-pressurisation of the system. Consequently, customer self-isolation and restoration in such situations is not considered within GL Noble Denton's model.

## 2.1 REVIEW OF INPUT DATA

In the report describing the self-isolation and restoration model and the cold weather model [4], GL Noble Denton has colour-coded the availability of the required data. Green denotes that data are available; amber indicates that little or no data are available, but suitable values can be inferred from engineering knowledge; and red denotes that no data are available and assumptions have had to be made. In cases where engineering judgement was applied, appropriate input values were chosen by a team of people at GL Noble Denton. Expertise from SGN was requested when appropriate.

In the following sections of this report, the data used in each part of the self-isolation and restoration model are reviewed in turn. Areas of concern are highlighted and suggestions for improving the model are presented.

### 2.1.1 Loss of Gas Supply

In the 'Loss of Gas Supply' section of the model the ability of a Gas Distribution Network to respond to a loss of supply is analysed: the number of available engineers and the number of properties that each engineer could visit per day are input. The values for these inputs have been chosen with reference to historical data from previous incidents. Assumptions have also been made regarding the proportion of customers who will be unable to undertake the self-isolation and restoration procedure themselves, and the proportion of customers who will refuse assistance from an engineer when offered.

### 2.1.2 Customer 1: Customer self-isolation and restoration (non-damaging contaminants)

If a gas supply failure occurs, the service to each individual property must be isolated. The 'Customer 1' section of the model calculates the probability that the service can be isolated by either the customer, a neighbour with access to the property or an engineer. In the absence of the customer or a neighbour, an engineer will only be able to isolate the service if the emergency control valve (ECV) is outside and accessible. These conditions are factored into the model. In the model, it is assumed that the longer the duration of the supply loss, the higher the probability will be that the customer can be contacted before the gas supply is reinstated. Therefore, the

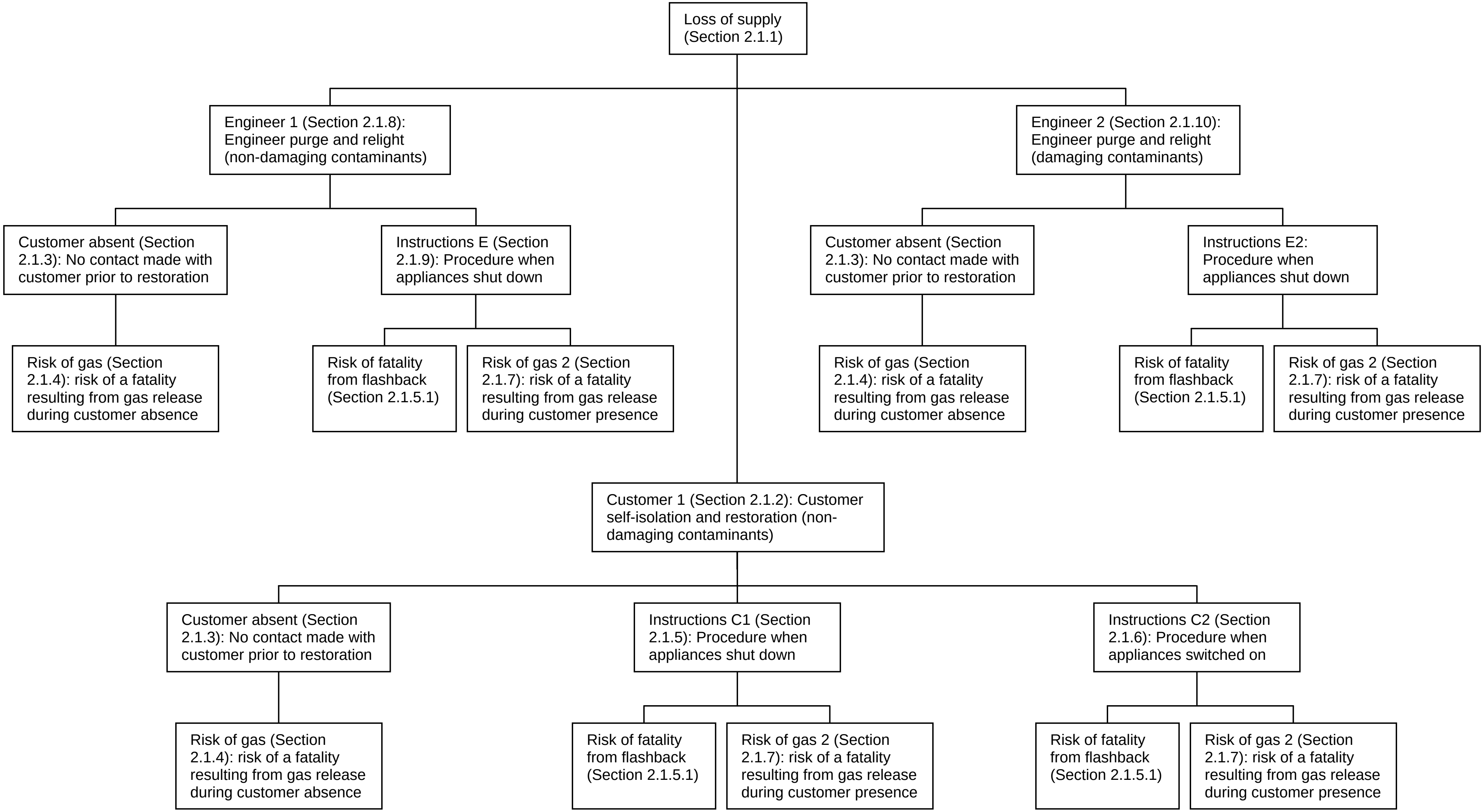


**Figure 1** Structure of the self-isolation and restoration model (adapted from information provided by GL Noble Denton)

probability that the service can be isolated is also dependent on the length of the supply loss. The values assumed for these inputs seem reasonable.

The model assumes that there is no risk of injury or fatality associated with the isolation process. However, in cases where the ECV is located in an inaccessible or difficult place this may not be true.

The probability that all the gas appliances in the property will be turned off once the service has been isolated is also input into this section of the model. It is assumed that the customer his/herself will be more likely to turn off all the appliances than a neighbour is. This input is dependent on the probability that the customer can be contacted and is therefore also dependent on the length of the supply loss.

#### *2.1.2.1 Duration of supply loss*

No information is available about the duration of previous loss of supply incidents. Therefore, GL Noble Denton has estimated the probability that a supply loss of a particular duration will occur. Five duration bands are considered in the model: less than 1 day; 1 to 3 days; 4 to 7 days; 7 to 14 days; and more than 14 days, and each has been assigned a probability of occurrence. For each duration band, the probability that the customer can be contacted within the time available (and thus the service isolated and appliances shut off) has been estimated. Weighted averages for the probability that the service can be isolated and the probability that the appliances can be shut off are then calculated, using the probability distribution for the duration of the supply loss. These averaged values are used within the model and, as a result, the values for these inputs are not actually dependent on the duration of the supply loss.

The duration of the supply loss will depend on whether the isolation and restoration procedures are carried out by the customer or by an engineer. The model would therefore be more robust if the simplifying assumptions described above did not have to be made. The need to estimate a probability distribution for the duration of the supply loss (and calculate weighted averages for the inputs that depend on this distribution) could be avoided if the results of the self-isolation and restoration model were presented in the same way as those of the cold weather model. In the cold weather model, described in Section 3, the number of fatalities per 1000 households is calculated, and this is expressed as a function of the duration of the supply loss. This approach has the further advantage that it offers consistency in the way the results of the two models are presented.

### 2.1.3 Customer absent: no contact made with customer prior to reconnection

The ‘customer absent’ section of the model considers the scenario in which the customer cannot be contacted. In such situations, there is a possibility that a gas device will have been left on in an unattended property. The following types of gas appliance are considered within the model: hobs and ovens (both built-in and free-standing); hall heaters (unflued); gas fires (both flued and unflued); boilers; and water heaters.

The probability that a gas device has been left on in an unattended property is calculated by first considering the population of these gas appliances in the UK. Statistics presented in the DTI report ‘*Assessment of the size and composition of the UK gas appliance population*’ [6] have been used. This report dates from 2005, but the general trends are still likely to be applicable today.

The probability that a particular gas device has been left on in an unattended property, and is still on when the gas supply is reinstated, is assumed to be dependent on the duration of the supply loss. The longer the supply loss, the more likely it is that the customer will return before the supply is reinstated and turn off the appliance. Engineering judgement has been used to determine these probabilities. Different values have been assumed for the probability that a built in hob is left on and the probability that a freestanding hob is left on. A justification for this should be provided, although GL Noble Denton's sensitivity study reveals that these inputs have a negligible effect on the model output.

For each type of appliance, GL Noble Denton has determined the probability that a flame supervision device has been fitted. These probabilities have been derived from a consideration of the expected age of appliance population and the dates on which relevant regulations were introduced. It is assumed that if there is a flame supervision device fitted to a particular appliance, there is no risk of a gas release on reinstatement of the gas supply, even if the appliance had been left on.

### 2.1.4 Risk of gas: risk resulting from gas release during customer absence

In the 'Risk of gas' section of the model, the risk of a fatality from a gas release in an unattended property is calculated. This situation can arise when the service has not been isolated, one or more appliances has been left on, and the property is still unoccupied at the point when the gas supply is reinstated.

The probability that a particular appliance has been left on is calculated from data entered in the 'Customer absent' section of the model.

#### *2.1.4.1 Probability of a flammable mixture forming*

The GL Noble Denton report [4] lists gas release rates for all the appliance types considered in the Self-isolation and Restoration model. Although no reference is quoted in the report, GL Noble Denton has confirmed that the majority of these gas release rates are taken from a previous report by Baldwin and Hopkins [7]. The gas release rates from individual appliances are not combined, even if these releases could potentially occur in the same room. Instead, the probability of a flammable mixture forming is calculated separately for each appliance. If the gas release rates were combined where appropriate, this could lead to a higher probability of a flammable gas-air mixture occurring, and thus a higher risk of a fatality. However, it is extremely unlikely that more than three of the appliances considered within the model would be located in the same room, so the current approach is probably satisfactory.

The gas concentration in a property of a given volume is calculated using an equation derived in Harris [8] and quoted in Appendix A of the GL Noble Denton report [4]. This is a standard equation that is also quoted in Lees [9]. The gas release rate from the appliance is used as an input to this equation, together with the volume of the room, the number of air changes per hour, and the time since the start of the release.

If the gas concentration in the room lies between the lower flammable limit (LFL) and the upper flammable limit (UFL), the mixture is flammable and an explosion may occur. To account for the uncertainties in the gas concentration calculation, the probability of a flammable mixture occurring is not set to zero outside these concentration limits. Instead, the probability of a flammable mixture occurring is assumed to gradually increase from 0% when no gas is present, to 100% when the LFL is reached. Above the UFL, the probability of a flammable mixture occurring is assumed to be 100% because for such concentrations to be reached, the gas concentration in the room must have passed through the flammable region defined by the LFL and the UFL. This approach is more cautious than using the LFL and UFL as absolute limits, and appears reasonable.

#### 2.1.4.2 Risk of fatality

Even if a flammable mixture is present, an explosion will only occur if an ignition source is present. In unoccupied properties, possible ignition sources include fridges and timers. The GL Noble Denton model assumes that the probability of there being an ignition source in an unoccupied property is 0.75. Historical data relating to ignition probabilities are limited and this seems to be a reasonable estimate.

The model assumes that if both a flammable mixture and an ignition source are present, an explosion will occur. The risk of a fatality from a gas explosion has been derived from data collated by GL Noble Denton on mains related incidents since 1990. The total number of fatalities has been divided by the total number of incidents to obtain a fatality rate of 0.268. The GL Noble Denton data set does not record whether the explosions occurred in occupied or unoccupied buildings, so fatality rates of 0.3 for occupied buildings and 0.2 for unoccupied buildings have been assumed.

HSL queried why the fatality rate for an unoccupied property is so similar to that for an occupied property. In response, GL Noble Denton agreed that a fatality rate of 0.2 for unoccupied buildings is probably too conservative, and stated that a value of 0.1 might be a better estimate and would still be erring on the side of caution [10].

A summary of data relating to domestic gas incidents is also available on the HSE website [11]. It would appear that the HSE data are more comprehensive, as far higher numbers of incidents are recorded than in the GL Noble Denton data set. If the total number of fatalities is divided by the total number of explosion incidents, a fatality rate of 0.09 is obtained from the HSE data for the period from 2003 to 2010. This value is significantly lower than that calculated by GL Noble Denton, and provides further evidence to support a reduction in the fatality rate that is assumed for unoccupied buildings.

The risk of a fatality has been calculated for each appliance separately, taking into account the probability that the particular appliance will have been left on. These values are then summed to give an overall risk of fatality. In the model, four separate calculations have been carried out for a hob, corresponding to 1, 2, 3, or 4 burners being left on. The results of these calculations should be combined using OR logic, not the simple summation that is currently used in the model. As it stands, this calculation will lead to an overestimate in the overall risk of a fatality. However, the sensitivity studies carried out by GL Noble Denton indicate that this will have a negligible effect on the model output.

If the correct procedures are followed, the Gas Distribution Networks will monitor unoccupied properties when the gas supply is reinstated, to check for gas leaks. GL Noble Denton’s model assumes that there is a high probability that this monitoring will take place when required and that appropriate action to secure the gas supply will be taken if gas is detected. The model accounts for the fact that the probability that gas will be detected during monitoring is dependent on the concentration of the air-gas mixture. Correct monitoring will significantly reduce the probability of an explosion occurring and thus the risk of a fatality.

### 2.1.5 Instructions C1: Customer self isolation and restoration – procedure when appliances shut down

The ‘Instructions C1’ and ‘Instructions C2’ sections of the model consider the scenario in which the customer can be contacted and is willing to carry out the self-isolation and restoration procedure.

The ‘Instructions C1’ section of the model calculates the risk of a fatality occurring as a result of a customer performing the restoration procedure in a property where all appliances have been shut down. To successfully complete the restoration procedure the customer must turn the Emergency Control Valve (ECV) on and then light a gas appliance (typically a ring on the hob), following the manufacturer’s instructions. It should be noted that the restoration procedure recommended for cases in which non-damaging contaminants (such as air) are present is the same as that recommended when the loss of supply has been caused by low pressure in the system. It is assumed that the contaminants will be purged from the system either before the gas lights or in the first few minutes that the gas is burning. Research carried out by British Gas [7] suggests that under these conditions the risk of an explosion from an air-gas mixture is remote.

Two possible causes of a fatality have been considered in the model, namely i) flashback following delayed ignition of the appliance, and ii) a gas explosion. A gas explosion may occur if the appliance is not successfully lit and the customer leaves the gas on, thus allowing a flammable mixture of gas and air to build up in the room. The risk of a fatality from a gas explosion is calculated by a separate part of model (entitled ‘Risk of gas 2’) and the assumptions and data used are reviewed in Section 2.1.7 of this report.

The model considers both the situation in which the ECV has been correctly isolated prior to restoration, and that in which the ECV has not been isolated. The risks associated with these scenarios are summed in the ‘Instructions C1’ worksheet and the overall result is transferred to the ‘Customer 1’ worksheet. This approach is incorrect, as these risks should be considered separately in the ‘Customer 1’ section of the model.

Engineering judgement has been used to estimate the probability that the appliance will light successfully when the customer attempts to carry out the restoration procedure and the probability that flashback will occur if the appliance does not light successfully. The assumptions that have been made appear reasonable.

#### *2.1.5.1 Risk of fatality from flashback*

In the model, all fatalities from flashback are assumed to occur as a result of a fall. The risk of a fatality from flashback is therefore calculated as the product of the probability of a fall as a result of flashback and the probability of a fatality as a result of a fall. The possibility that the shock of experiencing flashback could cause a customer to suffer a heart attack and subsequently die is not explicitly considered in the model. However, this sequence of events would also lead to a ‘fall’, so could be included implicitly in the chosen input values.

The probability of a fall as a result of flashback has been estimated from incident data reported by Baldwin [12]. Baldwin documents 20 flashback incidents, none of which led to a fall. A worst-case scenario of a fall occurring in one of the next 20 incidents is assumed, giving an upper bound on the probability of 1/40 = 0.025. This methodology is commonly adopted when limited historical data are available and no incidence of the event has been recorded. It may give a conservative result, but is an appropriate approach in this case.

GL Noble Denton has estimated that 0.18% of all falls in the home result in a fatality. This figure has been calculated from data in Table 4 of a report published by the Department of

Trade and Industry (‘*Avoiding slips, trips and broken hips – Accidental falls in the home*’) [13]. This table includes figures for falls classed as fatal, serious accidents and minor accidents. A serious accident is defined as one requiring admission to hospital for more than a day or one involving a fracture or serious laceration. In carrying out this review, HSL has assumed that a minor accident is any other accident that necessitates a visit to hospital, although this is not explicitly stated in the DTI report. GL Noble Denton has calculated the probability of a fatality by dividing the number of fatal falls by the total number of fatal, serious and minor falls.

HSL has several concerns about the use of this figure. The first of these is that longer-term fatalities do not appear to be included in the DTI data. The proportion of falls involving the elderly that eventually result in death is likely to be much higher than the figure quoted in the DTI report because, for example, a broken hip sustained in a fall often results in death some months later.

It appears that the data in the DTI report come from hospital admission statistics. If this is the case, falls that did not result in any injury will not have been included in the data. Therefore, the figure used by GL Noble Denton for the probability of a fatality from a fall (calculated by dividing the number of fatal falls by the total number of fatal, serious and minor falls) is likely to be a large overestimate of the true value.

The DTI report states that the majority of fatalities from falls occur as a result of falling down stairs. Experience suggests that it is more likely that a fall down stairs will result in a fatality than a fall on the level, but no data to support this assumption are provided in the DTI report because the fraction of falls that occur on stairs is not recorded. Hospital accident statistics [14] may provide more detail about the causes of falls. Of the categories of falls considered in the DTI report, only falls on the same level are relevant to flashback scenarios. Using data averaged over all types of fall may lead to an overestimate in the risk of a fatality from flashback.

The sensitivity studies carried out by GL Noble Denton reveal that the value chosen for the probability of a fatality from flashback has a significant effect on the model output. There is a large uncertainty associated with this input. The factors discussed above may balance out, but it is more likely that the value currently used in the model is an overestimate of the true value.

### 2.1.6 Instructions C2: Customer self isolation and restoration – procedure when appliances switched on

The ‘Instructions C2’ section of the model calculates the risk of a fatality in the event of a customer performing the restoration procedure having not shut down all the gas appliances. As in the ‘Instructions C1’ section, which models the restoration procedure when all appliances have been shut down, both the situation in which the ECV has been correctly isolated prior to restoration, and that in which the ECV has not been isolated, have been considered. As before, it appears that the risks associated with these scenarios have been combined incorrectly.

In common with the ‘Instructions C1’ section of the model, fatalities due to flashback and gas explosions have been considered. However, when not all the gas appliances have been shut down, any delay between reinstatement of the supply and an attempt at restoration will lead to an increase in the risk of a gas explosion, as gas may be released into the property in the intervening time. Furthermore, even after the restoration procedure has been started, gas may be released from appliances that have not yet been relit. These additional scenarios have been accounted for in the model.

### 2.1.7 Risk of gas 2: risk resulting from gas release during customer presence

In the ‘Risk of gas 2’ section of the model, the risk of a fatality from a gas release that occurs whilst the customer is present is determined. The output of this calculation is fed through to the ‘Instructions C1’ and ‘Instructions C2’ sections of the model, which calculate the risk of a fatality occurring as a result of a customer performing the restoration procedure. The same overall methodology is used as in the ‘Risk of gas’ section of the model, described in Section 2.1.4 of this report, but the values of certain inputs have been changed where appropriate.

In the event of a gas release, it is assumed that the gas concentration will build up in the property for a length of time equal to the delay between the gas supply to the property being reinstated and the customer attempting to relight an appliance. A value of 0.25 hours has been chosen for this input. This is an appropriate assumption in situations where the customer is unaware that gas appliances have been left on. However, if a gas release occurs because a customer fails to turn off the gas following an unsuccessful attempt to light an appliance, a much longer gas build up time would be possible. In turn, this would lead to there being a higher probability of a flammable mixture forming. In its current form, the model underestimates the risk associated with this scenario. However, GL Noble Denton’s sensitivity studies show that this will have a negligible effect on the model output.

More potential ignition sources, such as light switches and televisions, are present in an occupied property than an unoccupied property. GL Noble Denton has therefore increased the probability of an ignition source being present to 0.8. This appears to be a reasonable assumption. The fatality rate for an explosion in an occupied property is also assumed to be higher than in an unoccupied property, as more people will be in the vicinity. The value assumed for this input is discussed in more detail in Section 2.1.4.2.

The Gas Distribution Networks will not be monitoring occupied properties, so any gas release will be detected by smell rather than monitoring. However, the probability that the released gas is detected by monitoring appears to have been included in the calculation, presumably in error. This should be checked, and corrections made if appropriate. The model assumes that there is a 90% probability that the customer will smell the gas released.

### 2.1.8 Engineer 1: Engineer purge and relight (non-damaging contaminants)

The ‘Engineer 1’ section of the model considers the situation in which an engineer provides assistance to the customer or neighbour during the isolation process. In the model, it is assumed that the probability that all appliances will be correctly shut down will be higher than when the customer carries out the procedure alone (the ‘Customer 1’ section of the model), as guidance will be provided by the engineer.

### 2.1.9 Instructions E: Engineer purge and relight – procedure (non-damaging contaminants)

The ‘Instructions E’ section of the model calculates the risk of a fatality occurring as a result of an engineer performing the restoration procedure. The same calculations have been carried out as in the ‘Instructions C1’ section of the model, but input values have been changed where appropriate. It has been assumed that the probability that an engineer will successfully light an appliance is higher than that for a customer. Furthermore, the probability of a fatality due to flashback is assumed to be lower when an engineer carries out the restoration. It has also been assumed that the engineer will always shut off the appliance if it fails to light. These all appear to be reasonable assumptions.

Both the situation in which the ECV has been correctly isolated prior to restoration, and that in which the ECV has not been isolated, have been considered. As in the 'Instructions C1' and 'Instructions C2' sections of the model, it appears that the risks associated with these scenarios have been combined incorrectly.

In the parts of the model concerning engineer purge and relight, there is no section analogous to 'Instructions C2'. This means that the risk of a fatality in the event of an engineer performing the restoration procedure having *not* shut down all the gas appliances is not correctly calculated. HSL recognises that the probability of this occurring is low, but since the probability that all appliances are turned off under guidance from the engineer is not 1, this needs to be considered. The current modelling of the engineer purge and relight procedure does not account for the risk posed by a release of gas from an appliance that has not been shut down. This will lead to an underestimate in the risk of a fatality from the engineer purge and relight procedure.

#### 2.1.10 Engineer 2: Engineer purge and relight (damaging contaminants)

If damaging contaminants are present in the gas supply, the restoration procedure has to be carried out by an engineer. The 'Engineer 2' section of the model calculates the risk of a fatality associated with this procedure. This part of the model has not been reviewed in detail because it has no bearing on the decision as to whether self-isolation and restoration should be used.

## 2.2 DATA MANIPULATION AND EVENT TREE

In general, the input data seem to be combined in an appropriate way in the event tree using Boolean logic where required. However, in the course of this review, two errors were identified. These are described in the relevant parts of Section 2.1, and are summarised below for completeness.

### 2.2.1 Calculation of risks in sections 'Instructions C1', 'Instructions C2' and 'Instructions E'

In each of these sections of the model, both the situation in which the ECV has been correctly isolated prior to restoration, and that in which the ECV has not been isolated are considered. The risks associated with these scenarios are summed and the overall result is transferred to the 'Customer 1' or the 'Engineer 1' worksheet as appropriate. This approach is incorrect, as these risks should be considered separately in the 'Customer 1' and 'Engineer 1' sections of the model.

### 2.2.2 Gas releases from hob burners

In the model, four separate calculations are carried out to determine the risk of fatality associated with a gas release from a hob, which correspond to 1, 2, 3, or 4 burners being left on. The results of these calculations should be combined using OR logic, not the simple summation that is currently used in the model. As it stands, this calculation will lead to an overestimate in the overall risk of a fatality. However, the sensitivity studies carried out by GL Noble Denton indicate that this will have a negligible effect on the model output.

## 2.3 SENSITIVITY STUDIES

The sensitivity studies reveal that the number of fatalities predicted by the model is dominated by fatalities from flashback. The number of fatalities that is predicted to occur as a result of gas explosions is negligible in comparison. Therefore, decreasing the rate of fatality from an explosion in an unoccupied building, as suggested in Section 2.1.4.2, will not have a noticeable effect on the model output.

The number of fatalities that occur as a result of gas explosions is predicted to be low because the gas release rates modelled are rarely high enough for a flammable gas-air mixture to be formed. The gas release rates from individual appliances are not combined, even if these releases could potentially occur in the same room. Instead the risk of a fatality from an explosion is calculated separately for each appliance. If the gas release rates were combined where appropriate, this could lead to a higher probability of a flammable gas-air mixture occurring, and thus a higher risk of a fatality. However, it is extremely unlikely that more than three of the appliances considered within the model would be located in the same room, so the current approach is probably satisfactory.

The sensitivity studies show that varying the risk of fatality from flashback has a significant effect on the model output. Therefore, the risk of a fatality from a fall is a key input. There is a large uncertainty associated with the value that has been derived for this input. HSL recognises that the data required to reduce the uncertainty are unlikely to be readily available. However, users of the model should be made aware that the value chosen for this input is a cautious estimate with a large associated uncertainty.

## 2.4 MODEL OUTPUT

The output of the self-isolation and restoration model is a graph on which the number of fatalities is plotted as a function of the number of properties where a gas supply failure has occurred. Separate traces are plotted for the scenario in which customer self-isolation and restoration occurs and that in which a qualified person carries out the isolation and restoration. As would be expected, a much lower number of fatalities is predicted in cases where qualified personnel perform the isolation and restoration procedures.

The graph shows a linear relationship between the number of properties affected and the number of fatalities. It would therefore be possible to calculate the number of fatalities per 1000 affected properties and express this as a function of the duration of the supply loss, as is done in the cold weather model. As discussed in Section 2.1.2.1, this approach has the twin advantages of providing consistency between the outputs of the two models and avoiding the need to make assumptions about the duration of the supply loss.

## 2.5 CONCLUSIONS

HSL has reviewed the Self-Isolation and Restoration model and has concluded that the overall approach adopted by GL Noble Denton is appropriate. Self-isolation and restoration is a complex process to model and the overall event tree has been logically split up into smaller parts, which are considered on separate worksheets. Two possible causes of a fatality have been considered in the model, namely i) flashback following delayed ignition of an appliance during restoration, and ii) a gas explosion. The model assumes that there is no risk of injury or fatality associated with the isolation process. However, in cases where the ECV is located in an inaccessible or difficult place this may not be a valid assumption.

HSL has reviewed the input data used and identified areas of concern. The number of fatalities predicted by the model is dominated by fatalities from flashback, so the risk of a fatality from a fall is a key input. HSL has assessed the raw data used in the derivation of this input and has concluded that there is a large uncertainty associated with the chosen input value. It is probable that the value currently used in the model is a very cautious estimate.

The number of fatalities that is predicted to occur as a result of gas explosions is negligible in comparison to the predicted number of fatalities from flashback. Several small errors relating to modelling of gas explosions were identified during the course of the review, but none will have a significant effect on the model output. These errors are detailed in the relevant sections above.

In general, the input data have been manipulated correctly in the event tree and Boolean logic has been used where appropriate. However, an error has been identified in the way in which the risk of fatality has been calculated in sections ‘Instructions C1’, ‘Instructions C2’ and ‘Instructions E’. For the currently used input values, the effect of this error on the model output is small.

# 3. REVIEW OF COLD WEATHER MODEL

In the event of a gas supply failure, the temperature in an affected home will gradually drop to that of a property with no heating. GL Noble Denton’s Cold Weather Model attempts to quantify the number of additional fatalities that will occur as a result of this drop in the indoor temperature. The rate at which the house temperature drops has been related to factors such as the level of insulation and the availability of secondary heating. The corresponding increase in the fatality rate has been estimated from an analysis of the Excess Winter Death (EWD) rates determined by the Office for National Statistics (ONS) [15]. The model is in a spreadsheet format and its output is a graph that relates the predicted number of additional fatalities due to the temperature drop to the duration of the gas supply loss, for a series of outdoor temperature bands.

In the following sections of this report, the data sources and assumptions used in the model have been reviewed. Areas of concern have been highlighted and suggestions for improving the model have been presented.

## 3.1 INDOOR TEMPERATURE DROP DURING A GAS SUPPLY OUTAGE

When a gas supply failure occurs, affected properties experience a drop in indoor temperature. The assumptions made in the model regarding the rate at which the temperature drops, and the indoor temperature that is eventually reached, are discussed in the following subsections. The average indoor temperature prior to a gas supply failure has been assumed to be 17.5 ºC, based on information provided by the Department of Energy and Climate Change [16].

### 3.1.1 Temperature inside an unheated building

GL Noble Denton has assumed that following a gas supply loss, the indoor temperature of an affected property will eventually drop to that of an unheated building. The GL Noble Denton Phase 2 report [4] states that the temperature in an unheated building is usually around 2.78 ºC higher than the outside air temperature. This figure has been obtained from a website offering advice on home heating systems [17], which appears to be based in New Zealand. The website itself does not quote a source for this information. From the information provided on the website, it is not possible to ascertain whether the quoted figure is applicable to the types of housing found in the UK. However, the sensitivity studies carried out by GL Noble Denton reveal that the model output is not sensitive to this input, so no change to the model is warranted.

### 3.1.2 The effect of insulation

GL Noble Denton has assumed that the rate at which the indoor temperature drops from 17.5 ºC to a value 2.78 ºC higher than the outside air temperature is dependent on the level of insulation. The proportion of housing with different levels of insulation has been estimated from literature data [18]. In the absence of information about the rate at which the temperature drops inside an unheated home, it has been assumed that a fully insulated property will take seven days to cool down to a temperature 2.78 ºC above the outside temperature and that a property with no insulation will take two days to cool down to the same temperature. For properties with intermediate levels of insulation, linear interpolation between these two values has been used. The average time for a house to cool down has been determined from a weighted average, and is estimated to be 5 days. These assumptions seem reasonable, and the weighted average has been calculated correctly. The sensitivity studies reported by GL Noble Denton indicate that the Cold Weather Model is not particularly sensitive to the value chosen for this input.

### 3.1.3 Secondary heating

The number of properties with electric secondary heating has been estimated from literature data [19]. In general, secondary heating cannot be used to heat an entire house, so the model does not assume that the average indoor temperature of 17.5 ºC will be maintained in properties with electric secondary heating. The benefit of secondary heating is instead accounted for by assuming that the probability that a fatality due to cold weather will occur is 25% lower in houses with electric secondary heating. This approach appears reasonable.

## 3.2 ADDITIONAL FATALITIES

Data available from the ONS show that in England and Wales, the rate of mortality is higher during the colder winter months than during the rest of the year [15]. The additional deaths that occur in winter are referred to as Excess Winter Deaths (EWD). It has also been reported that the risk of an excess winter death occurring is higher in colder homes [20, 21]. GL Noble Denton's Cold Weather Model attempts to quantify the number of additional fatalities that could occur as a result of the lower house temperatures experienced during a gas supply loss. A relationship between the outdoor temperature and the number of additional fatalities in homes experiencing a gas supply failure has been derived.

### 3.2.1 The relationship between the outdoor temperature and the number of Excess Winter Deaths

GL Noble Denton has used the Excess Winter Deaths reported by the ONS as a measure of the number of additional deaths that occur as a result of cold weather. The annual number of Excess Winter Deaths is defined as follows:

Annual EWD = 4 × (average monthly deaths in winter - average monthly deaths in rest of year)

Winter is defined as the period from December to March inclusive. The number of deaths that occur in a particular winter is compared to the deaths that occur in the preceding August to November and the following April to July.

In GL Noble Denton's Phase 2 report [4], the number of Excess Winter Deaths has been plotted against the average winter temperature. A linear fit has been used to derive a relationship between these two variables. It has been assumed that at indoor temperatures of 12 ºC and above, the excess winter mortality rate is 0.01% of the mortality rate excluding Excess Winter Deaths. GL Noble Denton states that a non-zero value is assumed because even a small drop in indoor temperature may trigger hypothermia. It is clear from an inspection of this graph that there is not a strong relationship between the number of Excess Winter Deaths and the average winter temperature (the scatter about the best fit line is greater than the difference between the highest and lowest number of Excess Winter Deaths predicted by the fit, for the temperature range over which there is data). The very low $R^2$ value (0.079) confirms this conclusion. The available data only cover a small temperature range (approximately 3.6 ºC to 6.2 ºC), and the gradient of the line is essentially determined by the value chosen for the excess winter mortality rate at 12 ºC (the 'minimum Excess Winter Death rate').

#### *3.2.1.1 HSL review of this approach*

GL Noble Denton has attempted to link the number of Excess Winter Deaths to the average winter temperature. However, the average winter temperature may mask weather events that could have a significant effect on the number of Excess Winter Deaths, such as a cold snap in an otherwise mild winter. Analysis by Wilkinson et al. [21] suggests that there is a stronger relationship between the *daily* outside temperature and the number of Excess Winter Deaths.

In Figure 7 of the report by Wilkinson et al., the ratio of observed to expected deaths is plotted as a function of the outside temperature. This figure reveals that at temperatures below 20 ºC, the ratio of observed to expected deaths increases as the outside temperature decreases. A weak power relationship between the variables is predicted, but over the temperature range of interest, this could be approximated by a linear function. Unfortunately, the data available in the report by Wilkinson et al. cannot be easily converted into the number of Excess Winter Deaths for a given outdoor temperature because the report does not state how the number of 'expected' deaths is defined. If it is assumed that the expected number of deaths is equivalent to the number of deaths per day averaged over the whole year, the data can be presented in a similar format to that used by GL Noble Denton. HSL adopted this assumption and found that the gradient of the trend line in Figure 7 of Wilkinson et al. is similar to the gradient calculated by GL Noble Denton from the graph of Excess Winter Deaths as a function of average winter temperature. As discussed in Section 3.2.1, the relationship derived by GL Noble Denton is strongly dependent on the value chosen for the minimum Excess Winter Death rate. Furthermore, the sensitivity studies carried out by GL Noble Denton show that the model output is particularly sensitive to the value chosen for this input. HSL's simple comparison between the data used by GL Noble Denton and that presented by Wilkinson et al. suggests that an appropriate relationship between the average winter temperature and the number of Excess Winter Deaths can be derived by careful choice of this input. However, the use of data that shows a stronger relationship between temperature and number of Excess Winter Deaths, such as that reported by Wilkinson et al., would result in a more robust and reliable model.

### 3.2.2 The relationship between the indoor temperature and the number of Excess Winter Deaths

For a given outdoor temperature, GL Noble Denton uses the linear relationship discussed in Section 3.2.1 above to calculate the corresponding number of Excess Winter Deaths. A relationship between the indoor temperature and the number of Excess Winter Deaths is derived from the analysis of Wilkinson et al. [21], who state that there is a 20% difference in Excess Winter Deaths between the 25% coldest and the 25% warmest of homes. GL Noble Denton has therefore assumed that in the 25% coldest of homes there are 10% more Excess Winter Deaths than average, and that any house where there has been a gas supply failure will fall into this category. These additional Excess Winter Deaths are assumed to occur as a direct result of the gas supply loss. In the five days immediately after a gas supply failure, when the temperature within affected houses is still dropping, the number of additional Excess Winter Deaths is assumed to increase linearly from 0% to 10%.

#### *3.2.2.1 HSL review of this approach*

In the original Wilkinson et al. paper, Figure 6 plots the seasonal fluctuation in mortality in cold and warm homes. From a consideration of the area under the two traces, it would appear that the number of Excess Winter Deaths in the coldest homes is much more than 20% higher than the number of Excess Winter Deaths in the warmest homes. An absolute factor cannot be derived because each trace has been normalised relative to its summer minimum. It would therefore be of interest to know how Wilkinson et al. calculated the difference in Excess Winter Deaths between the coldest and warmest homes. This is of particular importance because independent analysis of the Wilkinson data by the authors of the Marmot report [22] suggests that Excess Winter Deaths are three times higher in the coldest quarter of housing.

In its analysis, GL Noble Denton has assumed that the temperature in a house affected by a gas supply failure is well represented by the average temperature in the 25% coldest of homes. However, the temperature in a property with no gas supply is likely to fall to a value much lower than this average value. Since mortality rates increase as the indoor temperature decreases

[21, 23], this may lead to an underestimate of the number of additional Excess Winter Deaths caused by the loss of the gas supply. This is of particular significance because sensitivity studies carried out by GL Noble Denton show that the model output is sensitive to the value chosen for this input.

GL Noble Denton's Cold Weather Model assumes that the excess fatality rate in affected households will be constant over the duration of the gas supply loss, once the initial drop in the indoor temperature has occurred. In the absence of detailed information about how prolonged periods of low indoor temperatures would affect the death rate, this appears to be a reasonable approximation.

## 3.3 DATA MANIPULATION

The input data appear to have been utilised in an appropriate manner in the Cold Weather Model. The equations quoted in the additional information provided by GL Noble Denton [5] and implemented in the spreadsheet model match the modelling assumptions given in the GL Noble Denton Phase 2 report [4].

## 3.4 MODEL OUTPUT

The output of the Cold Weather Model is a graph on which the number of fatalities per 1000 affected properties is plotted as a function of the duration of the gas supply failure, for a series of outdoor temperature bands.

### 3.4.1 Temperature bands

The five outdoor temperature bands considered in the model are below 5 ºC, 5 ºC to 9 ºC, 9 ºC to 12 ºC, 12 ºC to 16 ºC and above 16 ºC. The lowest band is represented by a temperature of 0 ºC, and the highest band by a temperature of 18 ºC. All other bands are represented by their mid temperature. As discussed previously, the number of Excess Winter Deaths increases as the outdoor temperature decreases. If a gas supply failure occurs in sub-zero temperatures, the model will currently return data relating to an outdoor temperature of 0 ºC. This is likely to lead to an underestimate in the number of additional deaths that will occur in such conditions.

One option for overcoming this problem would be to remove the concept of temperature bands. The model could be modified to calculate the predicted number of fatalities at regular outdoor temperature intervals (for example, every 2 ºC). The model output at each outdoor temperature could then be plotted as a separate trace on the graph. This modification to the model would require the relationship between the outdoor temperature and the number of Excess Winter Deaths to be extrapolated to lower temperatures, and should ideally be carried out in conjunction with a review of the data used to derive this relationship.

## 3.5 CONCLUSIONS

HSL has reviewed the Cold Weather model and has concluded that the overall approach adopted by GL Noble Denton is appropriate. However, HSL has some concerns about the suitability of some of the data sources used. In the model, the number of Excess Winter Deaths has been linked to the average winter temperature. However, there is not a strong dependence between these variables. Analysis by Wilkinson et al. [21] suggests that there is a stronger relationship between the *daily* outside temperature and the number of Excess Winter Deaths.

HSL's other principal concern is that the model may underestimate the number of additional Excess Winter Deaths caused by the loss of the gas supply. In its analysis, GL Noble Denton has assumed that the temperature in a house affected by a gas supply failure is well represented by the average temperature in the 25% coldest of homes. However, the temperature in a property with no gas supply is likely to fall to a value much lower than this average value, resulting in a higher number of additional Excess Winter Deaths than is currently assumed in the model.

It is important that appropriate values are chosen for the inputs discussed above, because sensitivity studies carried out by GL Noble Denton indicate that these are the two inputs that have the most significant impact on the model output.

The output of the model is a graph that relates the predicted number of additional fatalities due to the temperature drop to the duration of the gas supply loss, for a series of outdoor temperature bands. In the current version of the model, all temperatures below 5 ºC are represented by a temperature of 0 ºC. This is likely to lead to an underestimate in the number of additional deaths that will occur in sub-zero conditions.

# 4. OVERALL CONCLUSIONS AND RECOMMENDATIONS

SGN, acting on behalf of all the gas distribution network operators, commissioned GL Noble Denton to develop models to predict the anticipated number of fatalities from gas incidents during isolation and restoration and the anticipated number of fatalities from the effects of low indoor temperature during a gas supply outage. The outputs of these models will be used in the DNOs' prolonged gas supply failure contingency plans, to determine whether the gas supply to each affected property must be isolated and later restored by an engineer, or whether it is appropriate for the customer to perform these procedures his or herself.

HSE is responsible for assessing and validating the contingency plans for possible acceptance into the DNOs' safety case demonstration material. To aid this process, HSE asked HSL to carry out an independent review of the risk assessment models developed by GL Noble Denton. In this report, HSL has reviewed the assumptions made in the models, the data used, and the techniques used to manipulate the data. The review has concentrated on the inputs shown by GL Noble Denton's sensitivity studies to be the most important.

HSL has concluded that the overall approach adopted in the Self-Isolation and Restoration model is appropriate. Self-isolation and restoration is a complex process to model and the overall event tree has been logically split up into smaller parts, which are considered on separate worksheets. Two possible causes of a fatality have been considered in the model, namely i) flashback following delayed ignition of an appliance during restoration, and ii) a gas explosion.

The number of fatalities predicted by the Self-Isolation and Restoration model is dominated by fatalities from flashback, so the risk of a fatality from a fall is a key input. HSL has assessed the raw data used in the derivation of this input and has concluded that there is a large uncertainty associated with the chosen input value. It is probable that the value currently used in the model is an overestimate of the true value.

The number of fatalities that is predicted to occur as a result of gas explosions is negligible in comparison to the predicted number of fatalities from flashback. Several small errors relating to modelling of gas explosions were identified during the course of the review, but none will have a significant effect on the model output.

In general, the input data have been manipulated correctly in the event tree and Boolean logic has been used where appropriate. However, an error has been identified in the way in which the risk of fatality has been calculated in sections 'Instructions C1', 'Instructions C2' and 'Instructions E'. For the currently used input values, the effect of this error on the model output is small.

HSL has concluded that the methodology adopted by GL Noble Denton in the Cold Weather model is appropriate. However, HSL has some concerns about the suitability of some of the data sources used to determine the dependence of the number of Excess Winter Deaths on temperature and to determine the number of additional Excess Winter Deaths caused by the loss of the gas supply. It is important that appropriate values are chosen for these inputs, because sensitivity studies carried out by GL Noble Denton indicate that these are the two inputs that have the most significant impact on the model output.

Neither model accounts for the age or vulnerability of the affected customers. The majority of Excess Winter Deaths occur among those aged 75 or over [15], but it is also clear that the elderly are the population group most at risk of suffering a fatal fall during the restoration procedure [13]. It would be of interest to know whether the model outputs would favour the use of customer self-isolation and restoration if the input values were tailored to describe elderly customers. Such an analysis would have to account for the fact that, whether or not customer self-isolation and restoration is used, engineers will prioritise visits to the homes of the elderly or vulnerable. Furthermore, the guidance leaflets provided by the DNOs will recommend that the vulnerable do not carry out the self-isolation and restoration procedures by themselves.

## 4.1 RECOMMENDATIONS

As a result of its review, HSL recommends that certain corrections and modifications be made to GL Noble Denton's risk assessment models. These recommendations are listed by model in the following sections.

### 4.1.1 Self-Isolation and Restoration model

The following four recommendations are the most important of the recommendations relating to the self-isolation and restoration model, since the potential impact of the proposed changes on the model output is greatest.

- The DNOs and HSE may wish to consider whether the risk of a fatality occurring during the isolation procedure should be calculated within the model.

- The value chosen for the risk of a fatality from a fall in the home has a significant effect on the predicted number of fatalities. There is a large uncertainty associated with the value that has been derived for this input. HSL recognises that the data required to reduce the uncertainty are unlikely to be readily available. However, users of the model should be made aware that the value chosen for this input is a cautious estimate with a large associated uncertainty.

- The error in the methodology used to calculate the risk of fatality in sections 'Instructions C1', 'Instructions C2' and 'Instructions E' should be corrected.

- The output of the self-isolation and restoration model is a graph on which the number of fatalities is plotted as a function of the number of properties where a gas supply failure has occurred. HSL recommends that the graph be modified to show the number of fatalities per 1000 affected properties as a function of the duration of the supply loss.

The following recommendations relate to the sections of the model that consider the likelihood of a gas explosion occurring following reinstatement of the gas supply. The number of fatalities that is predicted to occur as a result of gas explosions is negligible in comparison to the predicted number of fatalities from flashback. Therefore, whilst it is important that the necessary corrections to the model are made, implementing these recommendations will not significantly affect the number of fatalities predicted by the model.

- The values assumed for the probability of a built in hob being left on and the probability of a freestanding hob being left on should be reviewed. If different values are chosen for these inputs, the reasoning for this should be provided.

- Four separate calculations are carried out to determine the risk of fatality associated with a gas release from a hob, which correspond to 1, 2, 3, or 4 burners being left on. The results of these calculations should be combined using OR logic, not the simple summation that is currently used in the model.

- HSL has identified a possible error in the methodology used to calculate the probability that a gas release will be detected by smell. This should be checked, and corrections made if appropriate.

- HSL recommends that the fatality rate for an explosion in an unoccupied building be reduced to 0.1.

- The 'Instructions E' section of the model should be modified to include a calculation of the risk of a fatality in the event of an engineer performing the restoration procedure having *not* shut down all the gas appliances.

### 4.1.2 Cold weather model

Implementation of the following recommendations will reduce the uncertainty associated with certain model inputs and allow greater confidence to be placed in the data on which the model is based. This will strengthen the case for incorporating the proposed contingency plans into the DNOs' safety case demonstration material. Therefore, consideration of the following recommendations should be given higher priority than consideration of the recommendations relating to the Self-Isolation and Restoration model.

- In the Cold Weather model, the number of Excess Winter Deaths has been linked to the average winter temperature. Analysis by Wilkinson et al. [21] suggests that there is a stronger relationship between the *daily* outside temperature and the number of Excess Winter Deaths. HSL recommends that the data in the report by Wilkinson et al. be reviewed to determine whether they can be converted into a format suitable for use in the Cold Weather model and that a literature search be carried out to identify other possible data sources.

- GL Noble Denton has assumed that the temperature in a house affected by a gas supply failure is well represented by the average temperature in the 25% coldest of homes. However, the temperature in a property with no gas supply is likely to fall to a value much lower than this average value. Since mortality rates increase as the indoor temperature decreases [21, 23], this may lead to an underestimate of the number of additional Excess Winter Deaths caused by the loss of the gas supply. The report by Wilkinson et al. [21] contains some information relating to the number of deaths within the 10% coldest of homes. This may provide a better representation of the situation in homes affected by a loss of gas supply. Therefore, HSL recommends that the report by Wilkinson et al. be reviewed, to determine whether the number of additional Excess Winter Deaths that occur in the 10% coldest of homes can be derived from the information provided.

- The output of the Cold Weather model is a graph that relates the predicted number of additional fatalities due to the temperature drop to the duration of the gas supply loss, for a series of outdoor temperature bands. In the current version of the model, all temperatures below 5 ºC are represented by a temperature of 0 ºC. This is likely to lead to an underestimate in the number of additional deaths that will occur in sub-zero conditions. Therefore, HSL recommends that temperature bands should not be used and that the model should be modified to calculate the predicted number of fatalities at regular outdoor temperature intervals. This modification to the model would require the relationship between the outdoor temperature and the number of Excess Winter Deaths to be extrapolated to lower temperatures, and should ideally be carried out in conjunction with the review of this relationship recommended above.

### 4.1.3 Implications of the recommendations

In the event of a loss of gas supply incident, the DNO will determine the number of households affected and the number of engineers available to respond to the incident. From this information, the expected duration of the supply loss can be predicted for the scenario in which all isolation and restoration procedures are carried out by engineers, and the scenario in which customer self-isolation and restoration is used. The graphs derived by GL Noble Denton will then be used to predict the anticipated number of fatalities from gas incidents and the anticipated number of fatalities from the effect of the weather, for both scenarios, and the results will be compared. For the majority of the test scenarios modelled by SGN using the graphs derived by GL Noble Denton, the use of customer self-isolation and restoration is strongly favoured. Specifically, the model predicts that the use of customer self-isolation and restoration will reduce the duration of the supply loss sufficiently that the increase in the number of fatalities arising during the restoration procedure will be outweighed by the decrease in the number of fatalities caused by exposure to low indoor temperatures.

If all the changes to the models recommended by HSL were implemented, it is probable that this would lead to an increase in the predicted risk of a fatality from low indoor temperatures and a decrease in the predicted risk of a fatality from customer self-isolation and restoration. Thus, for the majority of the test cases chosen by SGN, the conclusions reached using the model would not change, and for most of the scenarios, the case for using customer self-isolation and restoration would become even stronger.

Implementation of the recommended changes to the output graphs will require fewer assumptions to be made about key inputs (the duration of the supply outage and the outdoor temperature) and will provide consistency between the outputs of the two models.

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# Review of self-isolation and restoration risk assessment models


The gas distribution network operators (GDNs) must prepare emergency plans to respond to a widespread or prolonged loss of gas supply incident occurring on their part of the network. These plans are a requirement of the Gas Safety (Management) Regulations 1996 (GSMR) and form part of the safety case arrangements made by the GDNs.

This report provides an independent review of two risk assessment models that will be used in conjunction with the GDNs' gas supply emergency response plans. These models predict the anticipated number of fatalities from gas incidents during isolation and restoration of the gas supply and the anticipated number of fatalities from the effects of low indoor temperature that might be encountered during a gas supply emergency. The outputs of these models will be used by the GDNs to determine whether the gas supply to each affected property should be isolated and later restored by GDN-appointed personnel or by the gas consumer themselves.

This review covers the assumptions made in the models, the data used, and the techniques used to manipulate the data, and concludes that the overall approach adopted in the risk assessment models is appropriate. Some modifications to the models are recommended, but it is not anticipated that these modifications would affect the conclusions reached using the model, in the majority of cases.



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