Evacuation decisions in a chemical air pollution incident: cross sectional survey

S Kinra, G Lewendon, R Nelder, N Herriott, R Mohan, M Hort, S Harrison, V Murray

Abstract

Objective To compare the health outcomes in sheltered and evacuated populations after a chemical incident in a plastics factory.
Design Cross sectional survey.
Setting Urban area in southwest England.
Participants 1750 residents from the area exposed to the chemical smoke, of which 472 were evacuated and the remaining 1278 were advised to shelter indoors.
Main outcome measure Number of adverse health symptoms. A case was defined by the presence of four or more symptoms.
Main results 1096 residents (63%; 299 evacuated, 797 sheltered) provided data for analyses. The mean symptom score and proportion of cases were higher in evacuated people than in the sheltered population (evacuated: symptom score 1.9, cases 19.7% (n = 59); sheltered: symptom score 1.0, cases 9.5% (n = 76); $P < 0.001$ for both). The difference between the two groups attenuated markedly at the end of two weeks from the start of the incident. The two main modifiable risk factors for the odds of becoming a case were evacuation (odds ratio 2.5, 95% confidence interval 1.7 to 3.8) and direct exposure to smoke for more than two hours on the first day of the incident (2.0, 1.7 to 2.3). The distance of residence from the factory or level of exposure before intervention (first six hours) had little effect on the odds of a person becoming a case.
Conclusions Sheltering may have been a better protective action than evacuation in this chemical incident, which is consistent with the prevailing expert view. Although this study has limitations, it is based on a real event. Evacuations carry their own risks and resource implications; increased awareness may help to reduce unnecessary evacuations in the future.

Introduction

In the event of a chemical incident where the public may be exposed to a cloud of toxic vapour, two options of protective action exist—sheltering or evacuation. The prevailing expert view is to shelter.[1–4] However, this is based largely on experimental and modelling data, and we found no comparative data from actual incidents.

A fire started in a factory manufacturing plastic goods in southwest England. The factory was situated on an industrial estate adjoining a large residential area. The initial response of the emergency services was to start evacuating residents from their homes to a nearby leisure centre. This decision was subsequently reviewed and residents were advised to shelter and stay inside their homes. The resultant partial evacuation offered an opportunity to compare the relative health protection offered by these two modes of intervention. We therefore carried out a cross sectional postal questionnaire survey on residents in the affected area and compared the health outcomes among the people evacuated (one third) and sheltered (two thirds).

Methods

We produced a health questionnaire that was administered to all people living in the area that was exposed to the chemical smoke (evacuated 472, sheltered 1278).

Questionnaire

We modified the questionnaire from model questionnaires produced by the Chemical Incident Response Service (Guy's and St Thomas' Hospital, London) and National Focus for Chemical Incidents (Department of Health, Cardiff) (see bmj.com). The questionnaire went out at the end of the first week of the incident, with reminders at six weeks and two months.

Defining exposure and outcome

We identified the exposed population on the map by drawing a semicircular arc from the incident site in the direction of the greatest density of smoke, which we established by chemical meteorological data. The maximum distance from the factory included in the study was 1000 metres.

Since we did not have any direct measures of individual exposure we used two proxy measures: distance of the place of residence from the factory and an objective measure of relative exposure using modelling by the Met Office and data from the nearby meteorological station (see bmj.com for details). We used two time frames: the median time to evacuation (six hours) and the duration of the incident (48 hours).

We considered the exposure score for the initial six hours as the primary exposure, since it represents the actual exposure before the intervention, on which the

This is the abridged version; the full version is on bmj.com

Department of Social Medicine, University of Bristol, Bristol BS8 2PR
S Kinra *lecturer in epidemiology and public health medicine*

Public Health Development Unit, Plymouth Teaching Primary Care Trust, Plymouth PL1 2AD
G Lewendon *consultant in public health medicine*
R Nelder *public health information specialist*

Chemical Hazards Unit, Health Protection Agency, Guy's and St Thomas' Hospital Trust, London SE14 5ER
N Herriott *environmental epidemiologist*
R Mohan *research engineer*
V Murray *professor*

Met Office, Exeter EX1 3PB
M Hort *research scientist*

Southwest Peninsula Health Protection Unit, Devon Team, Dartington TQ9 6JE
S Harrison *consultant in communicable disease control*

Correspondence to: S Kinra Sanjay.Kinra@bristol.ac.uk

BMJ 2005;330:1471–5

decision was based. We also calculated a cumulative exposure score over 48 hours by adding exposures over time spent by the participant at each of the postcodes. Of the people who were evacuated, roughly two thirds went to the designated evacuation site (leisure centre), and the remaining third went to homes of friends and family. We obtained the postcode of the place where they stayed, and substituted these postcodes accordingly. The cumulative, 48 hour exposure score is difficult to interpret as it constitutes an inherent element of intervention, in addition to the participants being generally indoors (and so not necessarily exposed to that level of pollutants in the environment).

Acute symptoms produced by chemical smoke exposure are similar to those caused by common viral respiratory illnesses. We decided to define cases on the basis of number of symptoms. We established baseline prevalence of symptoms for the period (winter) by simultaneously administering the questionnaire to a random 10% sample (n = 1000) of residents from a neighbouring town with a similar demographic and socioeconomic profile. We calculated the mean symptom score for the residents of the unexposed town and regarded all those with a symptom score greater than 2 standard deviations of the mean as cases. We defined persistent cases similarly, but with symptoms persisting at the time of completing the questionnaire (at least two weeks from the time of the incident).

Data from environmental sampling and healthcare services

Environmental samples, based on the expected emissions, were taken repeatedly over a 48 hour period. Tests included hydrogen chloride, hydrogen cyanide, hydrogen fluoride, isocyanides, and styrene. The first air testing began some 12 hours after onset of the fire, inside and immediately outside the burning factory, in dense acrid smoke, and 100 metres downwind within the smoke plume. Other environmental investigations included tests for acidity of surface water; asbestos fibre counts; and levels of dioxins and furans. We collected information about health effects from people seeking medical help from ambulance and emergency departments, local general practitioners, and telephone helplines.

We used multiple logistic regression to estimate the likelihood of a person becoming a case for each of the independent risk factors.

Best model (R^2=0.15) for odds of becoming a case

Risk factor	Odds ratios (95% CI) Unadjusted	Adjusted*
Age in years	0.98 (0.98 to 0.99)	0.98 (0.97 to 0.99)
Distance of residence from factory (100 metres)	1.00 (0.99 to 1.00)	1.00 (0.99 to 1.00)
Exposure score before intervention (initial six hours) in g/m³	0.68 (0.09 to 5.08)	2.03 (0.19 to 22.07)
Evacuated	2.33 (1.61 to 3.38)	2.54 (1.68 to 3.82)
Spent more than 2 hours in direct smoke on first day	1.93 (1.65 to 2.26)	1.98 (1.67 to 2.34)
Asthma	3.34 (2.03 to 5.50)	3.21 (1.86 to 5.54)
Cigarette smoker	1.42 (0.88 to 2.29)	1.17 (0.69 to 1.99)

*Adjusted for other risk factors.

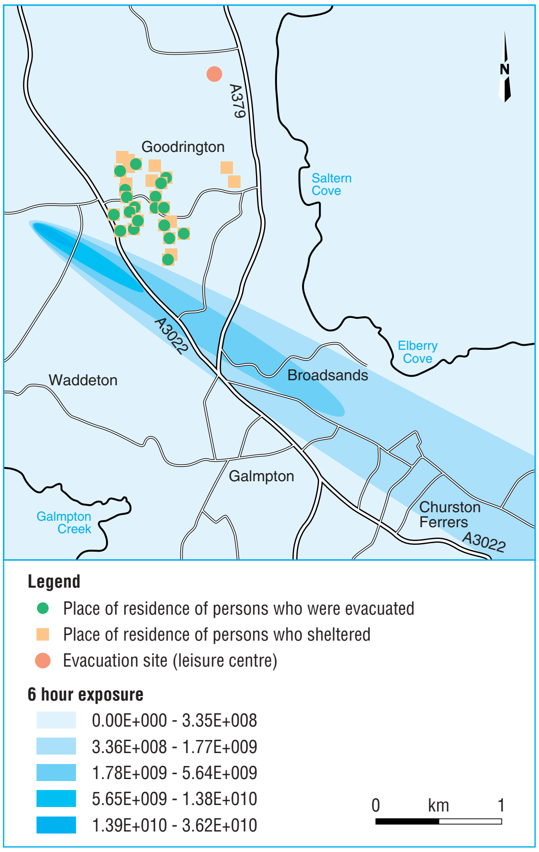

Fig 1 Location of residences by initial six hour exposure

Results

We received 1096 (63%) completed questionnaires from the exposed residents. The respondents were older and the proportion of female respondents was higher than among the non-respondents (respondents: median age 49 years, 53% female; non-respondents: median age 33 years, 46% female).

Of the people who received questionnaires in the adjacent unexposed town, 334 (33%) replied. The mean symptom score was 0.48 (SD 1.41). On the basis of this, we regarded all those with four or more symptoms as cases for the purposes of this study.

In the exposed area, the response rate (63%; respondents: 299 evacuated and 797 sheltered) and median response time (42 days; range: 1-66 days evacuated and 2-65 days sheltered) among the evacuated and sheltered populations were identical. Figure 1 and the calculated median distance from the factory (evacuated homes: 565 metres; sheltered homes: 572 metres; range for both: 217-791 metres) show that the evacuated and sheltered residents were similarly exposed to the smoke plume. Multivariate analysis showed that evacuation and direct exposure to smoke on the first day of the incident were the two main modifiable risk factors for the odds of becoming a case, while the actual distance of residence from the factory or the exposure before the intervention (initial six hours) seemed to be of little importance (table).

Of the people who had been evacuated, 195 went to the designated site (leisure centre) and 104 (35%) to homes of friends and family. We were able to calculate exposure scores for 73 of the people who were evacuated to other sites. The mean 48 hour exposure score (based on slightly fewer subjects, n = 1065) was similarly higher for the sheltered residents (evacuated 0.01 (SD 0.03) g/m^3 *v* sheltered 0.04 (0.11) g/m^3; $P < 0.001$), and contributed little to the odds of a person becoming a case (crude odds ratio 0.99, 95% confidence interval 0.99 to 1.00); unchanged after adjustment for all other variables in the table; fig 2).

Environmental sampling
The first air testing carried out 12 hours after the start of the incident, inside and immediately outside the burning factory, showed the maximum concentration of 5 parts per million of hydrochloric acid. Concentrations of other gases tested were less than 1 part per million. Tests 100 metres downwind within the smoke plume detected 1 part per million of hydrochloric acid and other gases below detection levels. Further tests carried out over the next two days found readings below detection levels. There were no other important environmental readings.

Health effects identified from people seeking medical help as a result of the exposure
Information available from medical inquiries (emergency services personnel (n = 31) and local residents (n = 23)) was of mild symptoms. Two people were admitted to hospital, one for acute attack of bronchial asthma and the other for suspected angina. Both had been evacuated and were admitted at the time of evacuation.

Discussion

In two groups of residents similarly exposed to smoke plume from a chemical incident, evacuation did not confer any additional health benefit over sheltering. If anything, evacuated residents seemed to have more ill health effects soon after the incident than sheltered residents, although the difference did not seem to persist beyond two weeks. Although our study has limitations, it is a comparative study that is based on a real incident. The results reinforce the prevailing expert view that favours sheltering over evacuation as a response to protect populations exposed to chemical air pollution incidents.

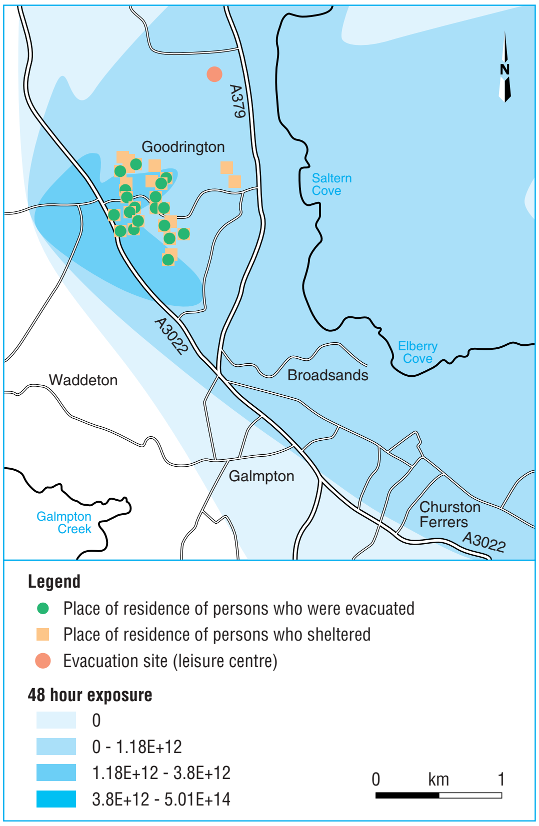

Fig 2 Location of residences by 48 hour exposure

What is already known on this topic

Populations exposed to chemical air pollution incidents are often evacuated by the emergency services as a means to safeguarding their health

Expert guidance favours sheltering indoors over evacuation as the emergency response; however, this advice is based on experimental and modelling data, and no comparative data from actual incidents exist

The lack of a good evidence base may be undermining adherence to expert guidance

What this study adds

Sheltering may have been a better protective action than evacuation in this chemical incident, which is consistent with the prevailing expert view

Evacuations carry their own risks and resource implications

Increased awareness may help to reduce unnecessary evacuations in the future

Limitations of the study
We have tried to estimate the exposure in two different ways: distance of the residence from the factory and atmospheric dispersion modelling of the pollutants. Although dispersion modelling of this type has some uncertainties, it is widely used, and, given the closeness of the meteorological station, the results would be expected to be of reasonable accuracy.[5]

Self reported symptoms in the people who had been evacuated could be a combination of physical effects of the smoke and the psychological impact of evacuation. In this context the perception of ill health is as relevant as physical ill health itself, especially with regards to long term psychological impact and anxiety. We looked at early health outcomes only, which may differ from long term health outcomes. Clustering of the responses and health effects among members of the same household is a limitation of this study. Results in another study that accounted for clustering remained largely unaltered.[6]

Comparison with other studies
Previous studies looking at the health effects of chemical incidents have entailed either sheltering or evacuation.[6 7 8-10] The theoretical basis for expert advice favouring sheltering over evacuation is that protection offered by barriers between the exposure and the population is at least as effective as the protection offered by increasing the distance between the

exposure and the population. Evacuations generally entail moving people through a much higher exposure, albeit for a shorter duration. Our results show that direct exposure to smoke is a more important determinant of ill health than the cumulative exposure to smoke. These results are consistent with other studies.[3 7]

Reasons for evacuation

Despite the expert guidance, an unacceptably high proportion of chemical incidents worldwide result in evacuations. Possible reasons include an instinctive response on the behalf of emergency services to evacuate populations in danger, and the preference to "play it safe" by first responders,[3] and delay in getting appropriate advice. Initial decisions are often taken under very stressful conditions. Lack of experience has also been proposed since greater frequency of evacuations is reported from areas where chemical incidents are uncommon.[11]

We thank the participants in this study for taking the time to complete the questionnaires. We also appreciate the help provided by Geoff Chamings and Shaun Carter at Devon County Council, who converted the postcode references into distance between the factory and the residences.

Contributors: See bmj.com

Competing interests: None declared.

Funding: None.

Ethical approval: Not required at the time. The study was carried out in 1999, when ethics approval was not considered an issue for such studies conducted by health agencies as part of their responsibility.

1 Purdy G, Davies PC. Toxic gas incidents—some important considerations for emergency planning. In: *The assessment and control of major hazards*. Rugby: Institute of Chemical Engineers, 1985.
2 NHS Executive. *Deliberate release of biological and chemical agents: Guidance to help plan the health service response*. London: Department of Health, 2000.
3 Essery G. On site emergency planning and the use of predictive techniques. *J Loss Prevention in the Process Industries* 1991;4:44-8.
4 Essery G. Chemical incident: evacuate or shelter. *Safety Health Practitioner* 1994;12:22-5.
5 Jones A, Thomson D, Hort M, Devenish BJ. *The UK Met Office's next-generation atmospheric dispersion model, NAME III. Proceedings of the NATO CCMS international technical meeting on air pollution modelling and its application (October 2004).* Banff, Canada: Kluwer (in press).
6 Morris, RD. *Human health effects of a spill of aromatic distillates in Superior, Wisconsin*. Atlanta: Agency for Toxic Substances and Disease Registry, Division of Health Studies, 1997.
7 Bauer U, Berg D, Kohn MA, Meriwether RA, Nickle RA. Acute effects of nitrogen dioxide after accidental release. *Public Health Rep* 1998;113: 62-70.
8 Baxter PJ, Heap BJ, Rowland MG, Murray V. Thetford plastics fire, October 1991: the role of a preventative medical team in chemical incidents. *Occup Environ Med* 1995;52:694-8.
9 Kizer KW, Garb LG, Hine CH. Health effects of silicon tetrachloride. *J Occup Med* 1984;26:33-6.
10 National Transportation Safety Board. *Railroad accident report—Derailment of Illinois central gulf railroad freight train extra 9629 East (GS-2-28) and release of hazardous materials at Livingstone, Louisiana, September 28, 1982.* Washington, DC: Bureau of Technology, 1983.
11 Sorenson JH. Evacuations due to off-site releases from chemical accidents: experience from 1980 to 1984. *J Hazardous Materials* 1987;14:247-57.

(Accepted 19 April 2005)

Commentary: Evacuation decisions in chemical incidents benefit from expert health advice

Peter J Baxter

Department of Public Health and Primary Care, University of Cambridge, Institute of Public Health, Cambridge CB2 2SR

Peter J Baxter *consultant occupational physician*

Pjb21@medschl.cam.ac.uk

Kinra et al have evaluated symptoms arising from a fire at a plastics factory that lasted 48 hours, in which partial evacuation of the area took place in the first six hours, with most residents remaining indoors for the rest of the emergency.[1] Statutory emergency planning and advice for people living around designated hazardous installations that manufacture or store chemicals has been based on mathematical modelling of the most likely scenarios for the catastrophic failure of storage vessels or other failures in the plant, in which the duration of flow of a cloud of chemicals that are accidentally released, neutral, or denser than air will be less than 30 minutes (the average time for countermeasures to be implemented).[2] Peak exposure to an individual living or working nearby at the time when such a chemical cloud disperses should be higher outdoors than inside a building with its doors and windows closed, at least for this short period of time. The difference will depend on how well the building has been sealed against the weather, to reduce normal air infiltration rates. Once the danger has passed, the emergency services would tell people to go outside into the fresh air. Attempts at rapid escape or evacuation are considered to be more dangerous than taking shelter indoors in such short term emergencies, but the adverse health consequences that may follow from this strategy—particularly the effects of exposure to low, cumulative levels of irritant gases in people with asthma and chronic lung disease who do take shelter—need to be studied whenever these unusual incidents occur.

This "stay indoors" strategy may not necessarily apply to certain chemical incidents of longer duration. Smoke from plastics fires usually contains a mixture of highly irritant substances, together with combustion gases, which for polyvinyl chloride (PVC) is mostly hydrogen chloride (HCl). Kinra et al measured 1 part per million of hydrogen chloride in the ambient air of the residential area on their first testing at 12 hours, and thereafter hydrogen chloride and other gases were undetectable. This very soluble gas is unlikely to produce any reactions in people with asthma at this concentration, and healthy individuals can be exposed to higher levels for prolonged periods without ill effects.[3] Other irritants in the smoke will have an additive effect. Acute incidents involving the inhalation of irritant gases (which are among the most important materials stored at major hazard installations and commonly emitted in fires) may, in severe cases, cause toxic pneumonitis and even death, and brief exposure may trigger reactive airways dysfunction syndrome (RADS; irritant induced asthma).[3] Kinra et al showed that the adverse respiratory consequences in people with asthma and others were few and concluded that remaining indoors was a safe option in the fire they reported.[1]

Temporary evacuation may nevertheless be advisable where a toxic release is threatened, such as in a