

Risk Reduction Strategy and Analysis of Advantages and Drawbacks for Acrylamide



Stage 4 Report

Prepared for
the Department of Environment,
Transport and Regions

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***Risk Reduction Strategy and Analysis of
Advantages and Drawbacks
for Acrylamide***

Stage 4 Report - March 2000

prepared for

The Department of the Environment, Transport and the Regions

by

Risk & Policy Analysts Limited,
Farthing Green House, 1 Beccles Road, Loddon, Norfolk, NR14 6LT
Tel: 01508 528465 Fax: 01508 520758

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EXECUTIVE SUMMARY

1. NATURE AND EXTENT OF THE RISKS

Both the draft environmental and human health risk assessments identified risks from the use of acrylamide and n-methylolacrylamide (NMA) grouts. Risks to the environment are to aquatic organisms following use that is not 'normal' (i.e. where some problem occurs that prevents the grout setting properly, allowing it to leak from its injection site to pollute watercourses and/or groundwater). Risks to human health are confined to workers under conditions of 'normal' use in large-scale operations where these grouts are applied. There are also considerable risks to workers following mis-applications.

The environmental risk assessment based its findings on two such mis-applications, in tunnels in Sweden and Norway. In both cases, the rate of water leakage into the tunnels was so rapid that it caused dilution of the grouts to the point where they could not set. In Sweden, nearby streams became contaminated with acrylamide and NMA, causing a fish kill and the paralysis of cows drinking from it. The major concern in Norway was contaminated drinking water. Both incidents also resulted in workers being exposed to high levels of acrylamide, although long-term effects have not been seen in either set of workers.

Consultation has not identified any producers, suppliers or users of acrylamide grouts within the EU. There are potentially two suppliers of NMA grouts within Europe, one of whom may be within the EU. Use of these grouts, however, is low due mainly to bad publicity following the incidents in Sweden and Norway but also because the grouts are expensive. Where these grouts are used, they are restricted to very specialised conditions which make up about 1% of all chemical grout applications.

2. PROPOSED RISK REDUCTION MEASURES

The potential for mis-application of the grouts needs to be reduced since this is associated with potentially serious environmental consequences as well as very high exposure for workers.

In this regard, four risk reduction measures are assessed by comparing their likely effectiveness, practicality, economic impact and monitorability. These options are:

- marketing and use restrictions (i.e. a ban on the use of grouts containing acrylamide and/or NMA);
- a certification system to ensure that only those with adequate training and experience can use these grouts (based on a voluntary agreement);
- specified 'conditions for use' based on those currently laid down for use of a grout containing NMA in the Copenhagen Metro Project, Denmark (also based on a voluntary agreement); and

- changes to the Material Safety Data Sheet (MSDS) and/or labelling system to make it easier to identify which grouts contain acrylamide and/or NMA.

One of the major constraints identified for the practicality of introducing the above risk reduction measures is that the exact chemical composition of the grouts (and in particular grouts containing NMA) is not always clear. The recommendation is, therefore, that the risk reduction measures should be applied in two phases. This is to ensure that the identification of the chemistry of the various chemical grouts becomes more transparent, making monitoring of the second risk reduction measure much more straightforward.

The recommendations for measures to reduce the risks (both environmental and to worker health) from the use of acrylamide and NMA grouts are:

- Phase 1: changes to the MSDS and/or labelling system to make the identification of grouts containing acrylamide and/or NMA much simpler; and
- Phase 2: the use of specified conditions of use each time these grouts are to be applied. These conditions should include details of the areas where the grouts can be used (for example, where the water is not used for drinking); a programme for testing, analysing and/or monitoring the chemistry of the water, soil and rock to allow early identification of problems; and the contractor must follow all of the safety instructions given in the manufacturer's information and/or as proposed by the contractor when producing a Method Statement to justify use of the grout.

3. BALANCING COSTS AND BENEFITS

The above risk reduction measures have been assessed mainly in qualitative terms. Nevertheless, it has been possible to provide some estimated costs and benefits for some of the proposed measures.

The costs associated with marketing and use restrictions are estimated as £5.1 million (€8.2million) based on the cost of moving to alternative grouts and the increased costs of pumping water from tunnels due to lost effectiveness. For specified conditions of use, costs have been estimated as £1.2 million (€1.9million), extrapolated from the costs of ensuring that future grouting activities at Romeriksporten would not affect drinking water. Costs have not been estimated for the certification system or changes to the MSDS/labelling system. However, they are expected to be higher than £1.2 million (€1.9 million) for the certification system and lower for labelling changes.

Benefits accruing from the risk reduction measures have been based on claims paid out following the incident at Hallandsås, at £1.9 million (€3 million). This will be an underestimate since it does not include all environmental and ecological damages.

Based on these figures, it can be seen that marketing and use restrictions appear not to be justified, given that the desired reduction in risk could be achieved through specifying conditions of use at a lower cost. These conclusions are, however, subject to uncertainty.

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List of Abbreviations

BCF	bioaccumulation factor
DBE	dibasic esters
DBP	dibutyl phthalate
EU	European Union
HSE	Health and Safety Executive
LC	lethal concentration
LD	lethal dose
MDI	diphenylmethane-4,4'-di-isocyanate
MOCA	methylene-bis-ortho-chloroaniline
MSDS	material safety data sheet
NASSCO	National Association of Sewer Service Companies
NATM	New Austrian Tunnelling Method
NMA	n-methylolacrylamide
NOEC	no observable effect concentration
NOK	Norwegian kroner
PACM	bis(p-aminocyclohexyl)methane
PEC	predicted environmental concentration
PNEC	predicted no effect concentration
PU	polyurethane
PV	present value
RA	risk assessment
SEK	Swedish krona
SME	small and medium enterprises
SNUR	significant new use rule
TDI	toluene di-isocyanate
TOC	total organic carbon
UK	United Kingdom
US	United States
US EPA	United States Environmental Protection Agency

1. INTRODUCTION

1.1 Background to the Study

Grouts containing acrylamide and/or n-methylolacrylamide (NMA) are used in sewer, manhole and pipeline repairs and as sealants in tunnels, around dams, to repair concrete and to stabilise ground. One such grout, Rhoca-Gil, was used in Sweden and Norway to reduce the rate of water leakage into tunnels. However, the grout did not set correctly allowing acrylamide and NMA to move out of the tunnel, polluting watercourses and poisoning workers.

As a result of these incidents, risk assessments on human health and the environment have been undertaken which show that there are potential risks from the use of these grouts to workers under normal use and to the environment following incidents such as those in Scandinavia. This suggests that risk reduction measures are required to minimise future risks from use of these substances.

The environmental Risk Assessment is being undertaken by the Building Research Establishment for the Environment Agency (Environment Agency, 1999), while the human health Risk Assessment is being conducted by the UK Health and Safety Executive (HSE, 1996a and b, 1999). Following the results of these Risk Assessments, the UK Department of the Environment, Transport and the Regions (DETR) contracted Risk & Policy Analysts (RPA) to develop the environmental risk reduction strategy, which should also have due regard for human health risks. However, this strategy does not attempt to comprehensively address risks to human health, as this will be done separately by HSE.

1.2 Substances Under Consideration

Acrylamide (CAS No. 79-06-1) has a molecular structure of $\text{CH}_2=\text{CH}-\text{CONH}_2$ and is available either as a solid or an aqueous mixture. It is primarily used in the production of polyacrylamide (99.9%) (HSE, 1996b). It is also used as a chemical intermediate to produce, for example, n-methylolacrylamide (NMA).

This risk reduction strategy considers the use of acrylamide and NMA in chemical grouts. Chemical grouts are those which gel with soil or rock following mixing to form an impermeable mass. Acrylamide and NMA grouts are typically used in the construction industry to seal water leaks. They have also been used in sewers and manholes for the same purpose.

Precise volumes of acrylamide and NMA grouts currently used within the EU is unknown, although many countries have said that they no longer use them (including Sweden, Spain and the UK).

1.3 Approach to the Study

It is the UK's responsibility under the European Union's Existing Substances Regulation (EEC 793/93) to assess the risks associated with the use of acrylamide and to propose controls to reduce these risks where they are considered to be too high.

The aim of this study was to evaluate the appropriateness of a range of risk reduction measures based on their likely effectiveness, practicality, economic impact, and monitorability (following the *Technical Guidance Document on Development of Risk Reduction Strategies*):

- the relative effectiveness of the measures in providing real reductions in environmental and human health risks, within acceptable timescales to all concerned;
- the practicality of implementing the measures and whether or not enforcement mechanisms already exist or new ones will be required;
- the economic impact of the measures in terms of the cost implications of risk reduction to producers, suppliers, users and to regulators;
- the monitorability of the measures in terms of whether or not they are effective and taking into account the nature of impacts on producers, suppliers, users and to regulators;
- the likely balance between the risk reduction benefits achieved and the costs of so doing for each measure; and
- whether any measures can be eliminated from further consideration given the conclusions drawn with regard to the above.

In order to assess potential risk reduction measures according to these criteria, we have undertaken a detailed literature review and consultation process. Annex 1 presents a list of those contacted during the study. The overall response rate was 45%, with a minimum of 34% responses from trade associations. All information given by these consultees is not directly sourced in order to preserve the confidentiality of responses. Sources are given, however, where data have been derived from published or publically available documentation.

This study is based on a largely qualitative assessment of both benefits and costs of reducing the risks from grouts containing acrylamide and/or NMA. Quantification has only been undertaken where relevant information was available, or where extrapolations could be made using data from other sources, such as the United States. This has been done to the extent possible for both the costs and benefits of the proposed risk reduction measures. Where extrapolation and assumptions have been used to allow limited quantification, all reasoning is given.

1.4 Structure of the Report

The remainder of this report describes the progress towards determining which risk reduction measure should be used to minimise or eliminate the risks from the use of grouts containing acrylamide and NMA:

- Section 2 covers the risks identified in the environmental and human health risk assessments, discusses the incidents at Hallandsås, Sweden and Romeriksporten, Norway and considers the substitutability of the alternatives;
- Section 3 considers the current use of grouts containing acrylamide and NMA, the types of risk reduction measures that are currently in place and describes the differences between the markets for chemical grouts in the United States and the EU;
- Section 4 then provides details on a range of risk reduction measures that could be proposed;
- Section 5 assesses the likely effectiveness, practicality, economic impact and monitorability of each of the risk reduction measures carried forward from Section 4. It also provides some quantification of the costs associated with each of the measures; and
- Section 6 summarises the findings of the study and proposes which of the risk reduction measures is the most suitable for acrylamide and NMA grouts.

1.5 Quality Assurance

A number of approaches to quality assurance have been used in the development of the risk reduction strategy for acrylamide and NMA grouts. Firstly, a range of stakeholders has been involved in the process, through a Steering Group managed by DETR. Members of this group have provided input to the study and have commented on previous drafts of the report. Secondly, a number of organisations within the grouting industry and acrylamide/NMA production more widely has been contacted to allow some validation of responses.

2. THE RISKS FROM ACRYLAMIDE AND NMA GROUTS

2.1 Summary of the Risk Assessments

2.1.1 The Draft Environmental Risk Assessment

Risks from the Production of Acrylamide and Polyacrylamide

The Risk Assessment concludes that ‘there is at present no need for further information and/or testing or for risk reduction measures beyond those being applied already’ for the production of acrylamide (Environment Agency, 1999). This is a conclusion (ii).

The production and use of polyacrylamide is also given a conclusion (ii) in the Risk Assessment, meaning there is no need for additional risk reduction measures.

Releases from the Use of Acrylamide and NMA Grouts

The Risk Assessment assumes that acrylamide and acrylamide based grouts have not been produced in the EU since 1997. A lack of information on current or historical levels of use meant it was not possible to calculate predicted environmental calculations on a regional scale.

Releases of 0.6 kg/day from uses in sewer and manhole repairs are estimated on the local scale using a number of default assumptions. These included an estimate of 1 to 3 tonnes of grouts used per year per company and assuming that grouting operations occurred for 250 days (5 days per week). This gives a total use of 12 kg/day which, assuming an acrylamide concentration of 5%, gives a maximum release of 0.6 kg/day. From this a C_{local} of 3.9 µg/l and $PEC_{\text{local (water)}}$ of 3.9 µg/l are calculated¹ (Environment Agency, 1999).

The conclusions of the Risk Assessment are that no further risk reduction measures are required at present for acrylamide based grouts used in sewer, manhole and pipeline repairs.

For construction uses, there was insufficient information to calculate predicted local concentrations based on use. Levels of acrylamide measured in streams and wells following the use of acrylamide and NMA grouts in tunnelling applications in Sweden and Norway were used instead. The Risk Assessment concludes that ‘there is a need for limiting the risks to aquatic organisms; existing risk reduction measures should be taken into account’ (Environment Agency, 1999).

¹ C_{local} is the local concentration of acrylamide released from acrylamide and NMA grouts; PEC_{local} is the local predicted environmental concentration from the use of acrylamide and NMA grouts.

2.1.2 The Human Health Risk Assessment

This aim of this risk reduction strategy is to minimise environmental risks. However, it is also important to consider the human health risks associated with the use of grouts containing acrylamide and NMA.

Risks from the Production of Acrylamide and Polyacrylamide

The human health Risk Assessment concludes that ‘there is at present no need for further information and/or testing or for risk reduction measures beyond those which are being applied already’ (a conclusion ii) for workers or consumers or from exposure via the environment from acrylamide/polyacrylamide (HSE, 1996a and b).

Releases from the Use of Acrylamide and NMA Grouts

The Risk Assessment concludes that risks to workers from ‘normal’ use of grouts containing acrylamide and/or NMA need to be limited (a conclusion iii (b)) in large-scale operations due to the potential for high exposure. This conclusion is also based on the low margin of safety values for neurotoxicity.

From small scale use, the level of exposure is likely to be negligible and it can be concluded that there is no cause for concern. Therefore, a conclusion iii (a) (there is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are already being applied) is reached and applies to the use of acrylamide grouts used in pipeline and sewer repairs and for manhole sealing.

The assessment of risks arising from use at Hallandsås is also given a conclusion iii (b) (there is a need for limiting risks to workers; risk reduction measures which are already being applied should be taken into account) following the high numbers of workers experiencing symptoms of exposure to acrylamide (HSE, 1999).

2.2 The Incidents in Sweden and Norway

2.2.1 Introduction

The need to reduce risks to the environment is based on the tunnelling applications in Norway and Sweden. These represent incidents rather than normal use of the grouts, therefore, it is important to have an understanding of these incidents for the development of appropriate risk reduction measures.

2.2.2 Hallandsås, Sweden

Overview

The tunnel through the Hallandsåsen ridge in the south west of Sweden was commissioned in 1991 to form part of the west-coast rail link between Gothenburg and Malmö. The project had earlier been classified as a ‘Missing Link’ (a bottleneck within

the European transportation system) and was intended to improve transportation between Oslo and Germany.

The ridge forms an important aquifer with considerable use made of the water for vegetable growing. The area is also of national interest, with high biological diversity and is protected by law to prevent harm to the natural or historic environment.

Tunnel construction began in 1992 and it was estimated that the total cost would be SEK 1,250 million (£93 million or €150 million²). Construction continued until October 1997 following the discovery that water seeping out of the tunnel had high acrylamide and NMA content. At this time, only one-third of the tunnel had been blasted at a cost of over SEK 1,000 million (£75 million or €120 million). Cows had also become paralysed from drinking the contaminated water and fish in a breeding facility on one of the affected water courses had been killed.

The source of the contamination was a chemical grout that had been used to seal the tunnel³. More than 1,400 tonnes of the grout, Rhoca-Gil, had been used which corresponded to an estimated 140 tonnes of acrylamide and NMA. Acrylamide and NMA were also found in groundwater.

It had become necessary to seal the tunnel using due to the high rates of water flow into the tunnel. Initially, the Rail Administration had requested permission to drain 33 litres per second from the entire tunnel. The aim was to seal the cracks by injecting concrete into the tunnel walls. However, this method did not work despite the use of large volumes of concrete. Indeed, the volumes of water being drained from the tunnel approached 70 litres per second. An alternative method of sealing the leak was, therefore, required and Rhoca-Gil was chosen.

The Impact of the Use of Rhoca-Gil on Workers

The methods used to apply the grout meant that workers were exposed to acrylamide and NMA. In total, 20 workers were found to be suffering from effects on the nervous system. Of these, nine were continuing to experience discomfort in Spring 1998.

However, the workers were only exposed to acrylamide for a limited period and it was concluded by the Swedish Environmental Protection Agency that the risk of long-term effects (including the development of cancer) was either zero or negligible (Anon, 1998).

The Impacts of the Discharge of Acrylamide and NMA on the Surrounding Area

Following the discovery that acrylamide and NMA were present in water discharging from the tunnel, a municipal emergency plan was put into operation. This involved

² Assuming there are SEK 13.4 to £1 and €1.6 to £1.

³ The fish kill may have been caused by a combination of acrylamide and/or the cement-based grouts with which the acrylamide-based grout was mixed.

recommendations as to the risks of drinking or using water supplies and in eating meat and vegetables produced in the region.

There were considerable impacts on commercial activities within the area, particularly on farmers. A total of 370 animals were slaughtered. Milk suppliers were also affected with 330,000 kg of milk disposed of and nine milk suppliers excluded from milk collection services. Vegetable and root crops were also destroyed.

Water was analysed from 310 wells in the area, with 29 having detectable levels of acrylamide and/or NMA. Water was delivered by tanker to households within the risk zone. Examination of people living within this zone, however, showed that there was no correlation between exposure to acrylamide/NMA and complaints about ill health.

The state of emergency was lifted in January 1998. However, the risk zone classification was not removed until March 1998 due to the lack of an agreed (or suitably sensitive) method for analysing the concentration of acrylamide in water. The total value of claims paid out as a result of the incident was SEK 26 million (£1.9 million; €3million) at the time of the publication of the Tunnel Commission's final report (Tunnelkommissionen, 1998).

What Caused the Problems?

The final report of the Tunnel Commission summarises that:

'The problems caused by the use of Rhoca-Gil were the result of a chain of errors and mistakes. There was no adequate analysis of the risks, and the relevant expertise was lacking. The information provided by the supplier was incorrect and was not checked. The safety organisation, company health care services and trade union representatives were not sufficiently involved. If the risks had been evaluated in advance and then followed up during the course of the project, these problems could have been avoided (Tunnelkommissionen, 1998).'

One of the major problems for the contractors was meeting the allowable limits for drainage of water from the tunnel as set by the Water Rights Court. The levels were set at such a limit that it is unlikely that grouting could ever have reduced leakage rates sufficiently.

There are also questions as to the adequacy of the environmental impact assessment. Rather than use the exercise to minimise impacts on the environment, the National Rail Administration described the problems as challenges and used the study to justify the project. No alternative approaches were considered.

Following the decision to use Rhoca-Gil, the County Administrative Board and the Municipality (the supervisory bodies for the project) decided that there was a need to consider the risks in greater detail. However, they did not contact the National Chemicals Inspectorate for another three weeks. Before any decisions could be made as to whether less hazardous materials should be used, streams, wells and groundwater had all been polluted with acrylamide and NMA. Also, the National Rail Administration had

not contacted the supervisory bodies until large-scale experiments with Rhoca-Gil had already begun.

Acrylamide and NMA leaked from the tunnel because it did not set correctly. This was because:

- the groundwater leakage rates were so high that they caused dilution of the components. This meant that polymerisation was slowed or could not occur;
- the temperature in the tunnel, less than 9°C, was too low and lay outside of the application range for the grout; and
- return flow from the process of injecting the grout into the rocks added to the concentration of acrylamide and NMA in water discharging directly from the tunnel.

It has been estimated that 5% to 15% of the grout remained in unpolymerised form, which is equivalent to 70 to 210 tonnes. This may be equal to 7 to 21 tonnes of unpolymerised acrylamide/NMA which could have been discharged from the tunnel (National Rail Administration, 1998).

2.2.3 Romeriksporten, Norway

The problems at Romeriksporten follow a similar path to that at Hallandsås, with the contractors attempting to reduce water leakage rates to meet pre-set guidelines. The problems with groundwater leakage were potentially more serious in Norway since there was a number of lakes which were undergoing dramatic decreases in water levels. North Puttjern Lake, for example, saw a decrease of 2m to 3m below its normal level in February 1997, with the level continuing to decrease throughout the year until it was 6m below normal in September. This caused a reduction in the lake's surface area from 4,000 m² to 1,000 m². Other lakes and bogs were also affected, including one lake used as an emergency water supply reservoir (NVE, 1999).

Grouting of the tunnel began in 1995 in an attempt to prevent loss of water in the lakes. However, by the end of July 1997 the grouting work had had very little effect. A total of 341 tonnes of Rhoca-Gil had been injected into the rocks between June 1995 and August 1997. The grout was used in combination with cementitious grouts. At this time almost Norwegian Kroner (NOK) 6 million (approximately £470,000⁴ or €750,000) had been spent on the grouting operation (Herbjørnsrud, 1997).

The tunnelling operation was already behind schedule following disagreements over the value of the contract to the parties involved with its construction. The high leakage rates put the tunnelling project even further behind.

In October 1997, it became known that the grouting material used at Romeriksporten was the same as that used at Hallandsås. Tests were then undertaken to assess whether the

⁴ Assuming 12.8 NOK to £1.

lakes had been contaminated with acrylamide. These tests found that there was a concentration of 140 µg/l of acrylamide and 42 µg/l of NMA on the 7 October 1997, which decreased to lower levels on 9 October 1997. Contamination of drinking water was also found (NOU, 1999). This is equivalent to 560 times the limit value set by the EU (0.25 µg/l).

One of the major concerns in Norway was that cancer-producing chemicals could be used in large volumes without the knowledge of the authorities or local inhabitants contrary to national legislation. It was not known that the grout contained acrylamide until August 1997 as the information provided by Rhone-Poulenc, the producers, had not stated it.

As the contractors had not previously known that the grout contained acrylamide, workers had been exposed to it. A statement by one worker indicated that respirators were not used and that the vapours inside the tunnel were so strong that they suffered from headaches. One of the workers was also not wearing a hood and water from the boreholes (probably including Rhoca-Gil) ran down the back of his neck (Hustadnes, 1997). This is somewhat anecdotal but highlights that the safety instructions given with Rhoca-Gil were not followed.

Health checks and blood tests were taken from 23 tunnel workers who had been involved with the injection of Rhoca-Gil plus an additional 20 tunnel workers who may have had some contact with the grout. Blood tests taken shortly after the incident found that three workers did have elevated levels of acrylamide. These workers had been recently exposed. Examinations one year later found that symptoms had decreased in almost all cases, with statistically significant decreased in cases of nausea and dizziness (a decrease of 32%); and eczema/skin irritation (a decrease of 25%). Table 2.1 presents some of the symptoms and the changes between the first examination (shortly after the incident) and the second (one year later).

None of the workers who had been exposed were found to have lasting health effects when examined two years after the incident (Dag sa Visen, 1999).

2.3 The Implications of the Incidents

Following the incidents at both Hallandsås and Romeriksporten, Rhone-Poulenc stopped production of Rhoca-Gil.

As a result of the problems at Hallandsås, a number of major construction companies have introduced environmental management systems for site operations. These systems should ensure an increased level of environmental expertise and should clarify the various levels of responsibility.

Symptom	% suffering from Symptom	
	Just After Incident	One Year Later
Tingling sensation in hands	43.8%	20.8%
Headache	27.3%	12.0%
Tingling sensation in feet	30.4%	25%
Nausea/dizziness	40.0%	8.3%
Difficulty concentrating	25.0%	12.5%
Cough	40.9%	20.0%
Throat irritation	34.8%	16.0%
Eczema/skin irritation	37.5%	12.0%
Flaking skin on hands	37.5%	16.0%

Source: Statens Arbeidsmiljøinstitutt (1999)

The Tunnel Commission (Tunnelkommissionen, 1998) also included proposals that:

- all major infrastructure projects must be subject to environmental review;
- environmental impact assessments must always include an environmentally friendly alternative (where this is the best option from the environmental perspective);
- users of large quantities of chemicals should be obliged to inform their supervisory bodies before use of the chemical begins;
- initiatives are required to ensure better compliance with EC legislation; and
- the user of chemicals should be able to check the information provided to them by suppliers.

The discovery of unacceptable levels of acrylamide and NMA in drinking water in Norway resulted in a number of alternative solutions to controlling the leak being put forward. The preferred solution (based both on cost as well as the estimated time it would take before the leak is expected to reduce) was continued grouting, this time using a polyurethane grout. Concerns were then raised over the safety of these grouts, particularly by the Norwegian Environmental Group, Bellona. Questions have also been raised as to the likelihood of success of continued grouting.

2.4 The Alternatives, Their Effectiveness and Relative Risks

2.4.1 Overview

The main chemical grout alternatives to acrylamide and NMA grouts are:

- acrylics and acrylates not containing NMA;
- polyurethanes;
- silicates; and
- formaldehydes.

Other grouts which may also be alternatives in certain situations include:

- epoxies;
- cementitious grouts (including microcements); and
- bentonite grouts.

There is not always a clear distinction between each of these types of grout since many of them can combine similar components to suit the conditions of the site. For example, silicate grouts can be mixed with cements for many applications.

2.4.2 Acrylamide and NMA Grouts

The major advantage of grouts containing acrylamide and NMA is their very low viscosity (similar to water). This allows the grout to penetrate the same voids and cracks as water. Hence, once the grout has set it seals the whole rock or soil mass preventing water from entering.

Acrylamide and NMA grouts are also very versatile having a large application range and with setting times that can be altered to suit the requirements of the user. Set times can be closely controlled from a few seconds to several hours. In addition, NMA grouts can be used in a wide range of conditions, including in flowing water (although concentrations need to be higher). However, the Technical Data sheets recommend that the concentration of the grout (usually diluted with 1 to 3 parts of water) should be higher.

The major disadvantages with these grouts are the environmental and health risks and bad publicity that are associated with their use. Acrylamide grouts also form weak gels (high water content) which can be susceptible to erosion from the ground or shrink-swell when the moisture content of the ground is variable.

The materials safety data sheet provided with a grout containing NMA states that the grout has an immediate acute health hazard and a delayed chronic health hazard. Prolonged contact with the grout may cause muscle weakness, bluish cold hands, peeling of skin on the palms of the hands, numbness and a tingling sensation in limbs. Accumulative effects can lead to central nervous system disturbances (Avanti, 1999). Acrylamide is also considered a probable carcinogen.

In addition, these grouts tend to be expensive within the EU and so are most likely to be used in combination with other, less expensive grouts to fill in the remaining voids.

2.4.3 The Requirements of a Suitable Alternative

Types of Application

There is a wide range of potential applications for grouts, with the most suitable grout for any particular situation being determined by a large number of factors. Table 2.2 summarises the types of application where each of the various alternatives can be used.

Grout Type	Uses ¹					
	Sewers/ Manholes	Soil Stabilisation	Mines	Tunnels	Containment (waste, etc.)	Crack Sealant
Acrylamide	✓	✓	✓?	✓	✓?	✓
Acrylic	✓	✓		✓?		✓
Acrylate	✓			✓	✓	
Polyurethane	✓	✓	✓?	✓	✓	✓
Epoxy	✓				✓?	
Silicates		✓	✓?	✓	✓	
Formaldehyde		✓	✓?	✓	✓	
Methyl methacrylate	✓	✓				
Cement-based (including microcements)		✓	✓	✓	✓?	✓
Bentonite-based		✓	✓	✓		✓?

Source: Consultation; various Internet sites including (<http://www.avantigrout.com>), (<http://www.deneef.net>), (<http://www.webac.com>), (<http://www.mmm.com>), (<http://www.mapei.com>), (<http://www.fosrocusa.com>)

Notes: ¹ this is a guide only as consultation indicates the most suitable grout for each use will depend upon many factors

The most popular grouts for construction in the UK and Europe are sodium silicates and sodium aluminates. These grouts also form the main alternatives to acrylamide and NMA grouts. Cement, microcement and bentonite grouts are also widely used due to their relatively low costs (since these cements do not require specialist equipment or a high level of training).

One type of microcement has been used successfully on a number of occasions in Spain as an alternative to acrylamide and NMA grouts. Similarly, pure Portland cements have been successfully used in Norway even where the rock conditions were unfavourable.

The sewer repair industry tends to use acrylics/acrylates and polyurethanes, with each accounting for 50% of sewer repairs involving grouting. Polyurethanes are the main alternative to grouts containing acrylamide and NMA. Epoxies tend to be used in smaller diameter pipelines. Epoxies also only seal the surface unlike chemical grouts which penetrate through to the depth of the crack. Cementitious injection is useful for point source problems, but can become very expensive (and slow) if there are a significant number of leaks. Silicates have the advantages of being able to seal all types of leak in one treatment, and it is also inert. However, this can be expensive (Jones, 1998).

Viscosity and Particulate Content

Acrylamide and NMA grouts are estimated as making up only 1% of the total use of grouts indicating that, in most situations, the alternatives are readily substitutable. It is the use of these alternative grouts in small voids and cracks which is the key to determining whether they are totally substitutable.

The viscosity of the alternatives is not always comparable with water meaning that they may not be strictly substitutable. This is one of the problems that has been emphasised in the United States by the producers, suppliers, trade associations and users of acrylamide and NMA grouts. Indeed, the United States Environmental Protection Agency (US EPA) has since agreed to remove NMA grouts from the proposed ban on acrylamide grouts.

The viscosities of the alternatives are generally highly variable, and can be lowered by increasing the temperature. Potentially, therefore, it may be possible to use the alternatives in situations where acrylamide and/or NMA would be preferred. The disadvantages with heating the grouts are (a) the energy required (b) the potential dangers of applying hot liquids and (c) the potential for altering the nature of the surrounding material (particularly soils). Typical viscosity ranges for each of the alternatives are given in Table 2.3.

The particulate content can also affect the types of voids and cracks which the grout will enter. This is also a measure of how 'clean' a grout is. For example, formaldehyde-type grouts have a very low particulate content which means that they can penetrate very small cracks. Silicate grouts similarly will penetrate into these cracks. Cement and bentonite grouts tend to have higher particulate contents and so are unable to enter these cracks and, hence, need to be used in association with a cleaner grout.

This was the type of approach used in the Jubilee Line (on the London Underground), where 35,000 m³ of grouts were used. A technique called blanket grouting was used to prevent fractures in the overlying Thames gravels breaking through the clay and causing serious ingress of water into the tunnels. Cement and bentonite grouts were used to seal the largest cracks with sodium silicate used for the smaller cracks. Cement and bentonite

grouts were preferred for the larger cracks because they are less expensive than the silicates.

Chemical Stability

The chemistry of the grouts determines the chemical and/or physical conditions that will affect both the application and stability of the grout. Most grouts are not affected by attack from fungi, bacteria, dilute acids, alkali and ordinary salts and gases normally found within the ground. It is under more severe conditions where the chemical stability may differ.

Grout Type	Viscosity range¹
Acrylamide	1 to 2 centipoise
Acrylic ²	1 to 2 centipoise
Acrylate	1 to 3 centipoise
Polyurethane	10 to 900 centipoise
Epoxy	600 centipoise
Silicates	2 to 5 centipoise
Formaldehyde	1 to 2 centipoise(?)
Microcement/Cement-based	25 to 250 centipoise ³
Bentonite-based	~20 centipoise

Source: Consultation; various Internet sites including (<http://www.avantigrout.com>), (<http://www.deneef.net>), (<http://www.webac.com>), (<http://www.mmm.com>), (<http://www.mapei.com>), (<http://www.fosrocusa.com>), (<http://www.ugc.mbt.com>)

Notes: ¹ this is provided as a guide only; some of these types of grout may have viscosities which differ from these typical ranges
² some acrylic grout may contain NMA
³ the lower viscosities relate mainly to microcements

Acrylamide grouts are very stable when in contact with chemicals normally found in the ground and with chemicals commonly found in sewer systems. They are affected, however, where the moisture content is variable. This can cause shrinkage of the grout within the pores which would allow water to penetrate. Acrylate grouts have a similar chemical stability to acrylamide but may swell in the presence of water.

Silicate grouts have a fairly high resistivity, particularly to acids, alkalis and salts normally found in the ground. They are also resistant to fungi and bacteria and are stable under conditions of freeze-thaw. In order to ensure permanence of the silicate gel, neutralisation of the sodium silicate is necessary.

Silicate grouts can also be used as a direct alternative to polyurethane grouts in most conditions. They are, however, not always suitable in the most severe conditions, such as attack by stronger organic solvents, acids, alkali and microorganisms. Polyurethanes tend to be stable against all of these types of chemical attack. Hydrophobic polyurethanes are not affected by changes in the moisture content of the soil or ground.

Cementitious grouts also have very high durability, being suitable for use in sea water, stabilisation of hazardous waste and nuclear waste containment. They are also resistant to shrinkage and corrosion. Cement grouts routinely last for 100 to 200 years without eroding out of the ground, even under flowing water conditions.

Environmental Effects

Information on the environmental effects of the alternative grouts has been difficult to obtain. There are some data available on the effects of some of the chemicals which form part of the composition of these grouts, particularly for di-isocyanates (both toluene di-isocyanate (TDI) and diphenyl-4,4'-di-isocyanate (MDI)) and dibasic esters. These chemicals are present in the two most commonly used alternatives, polyurethanes and silicates. However, the lack of comparable measurements means that there is considerable uncertainty within the comparisons of risk given below.

Acrylamide is readily biodegradable at lower concentrations. At higher concentrations there may be a time lag between initial dosing and the onset of rapid degradation. Acrylamide has a low bioaccumulation factor in fish, estimated as being between 0.26 (*Cyprinus carpio*) and 1.65 (viscera of *Oncorhynchus mykiss*).

Table 2.4 presents comparisons of toxicity data for some of the chemicals commonly found in grouts. However, the data are such that it is difficult to obtain direct comparisons, hence, only those species where there are two or more measurements are shown. Comparisons are further restricted since some of the data refers to a 100% concentration of the chemical, others relate to the formulation of the grout. Hence, the conclusions drawn below are indicative only and are not intended as a guide to relative toxicity.

Considering those species which have more than two comparisons shows that:

- *Oncorhynchus mykiss*: methylmethacrylate, methacrylic acid and dibasic esters are more toxic to rainbow trout than acrylamide;
- *Daphnia magna*: acrylamide is less toxic than methylmethacrylate but more toxic than methacrylic acid for this species. Dibutyl phthalate (DBP) is the most toxic (although this would only form one of many constituents in a PU grout);
- *Selenastrum capricornutum*: acrylamide is more toxic than methylmethacrylate but less toxic than methacrylic acid for this freshwater algae. Dibutyl phthalate has a very high toxicity to freshwater algae;

Table 2.4: Selected Toxicity Comparisons for Chemicals Commonly found in Grouts							
Species	Measure	Toxicity of Chemical/Grout (mg/l)					
		Acrylamide	NMA	Methyl methacrylate	Methacrylic acid	Polyurethane grouts	Silicate grouts
<i>Fish, Invertebrates, Freshwater Algae</i>							
<i>Lepomis macrochirus</i> (bluegill sunfish)	96 hr LC ₅₀	100		191		DBP: 0.7-1.4	
<i>Onchorynchus mykiss</i> (rainbow trout)	96 hr LC ₅₀	110		>79	85	LC ₀ >1000	DBE: 18-24
	96 hr NOEC	37		40			
<i>Daphnia magna</i> (aquatic invertebrate)	48 hr EC ₅₀	98		69	>130	DBP: 3.4	
<i>Selenastrum capricornutum</i> (freshwater algae)	72 hr EC ₅₀	33.8		>200	20-45	DBP: 0.75	
<i>Mammals</i>							
Rat	Oral LD ₅₀ (mg/kg)	107-203	>3000		1320	MDI: >15000 PACM: 380 DBP: >5000	DBE: 8191 grout: >2000
Rabbit	Dermal LD ₅₀ (mg/kg)	1150	>2000		50-100	MDI: 5000 PACM: 2110 DBP: 2000	DBE: >2250
Rat	Inhalation 4h LC ₅₀ (mg/l)				7.1	MDI: 490 DBP: 15.68	>11
Source: Environment Agency (1999), HSE (1996b), Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (1999a and b), consultation, IUCLID database, Technical Information and MSDS for the relevant substances Notes: MDI - diphenylmethane-4,4'-di-isocyanate; PACM - bis(p-aminocyclohexyl)methane; DBP - dibutyl phthalate; DBE - dibasic ester							

- rat (oral): acrylamide has the highest toxicity whilst NMA grouts have very low toxicity (>3000 mg/kg); and
- rabbit (dermal): methacrylic acid is the most toxic, with acrylamide second. NMA grouts, PACM (PU grouts) and DBE (silicates) all have LD₅₀ greater than 2000 mg/kg.

Polyurethane (PU) grouts contain a mixture of a large number of chemicals, some of which are significant in terms of environmental toxicity. These can include:

- toluene di-isocyanate (TDI) and diphenyl-methane di-isocyanate (MDI);
- bis(p-aminocyclohexyl)methane (PACM);
- dibutyl phthalate (DBP); and
- methylene-bis-ortho-chloroaniline (MOCA).

The concentration of these chemicals in the PU grout is variable and TDI and/or MDI are often one of the main constituents of one of the components. A PU grout considered for use at Hallandsås and Romeriksporten, for example, contains between 20 and 60% MDI and between 30 and 60% DBP (Bergfald, 1997).

DBP and MOCA have the potential to bioaccumulate. DBP, for example, has a bioaccumulation factor (BCF) of 4.72. MDI and TDI would not be expected to bioaccumulate since they react rapidly with water. DBP is considered to be an animal teratogen whilst TDI has been shown to cause pancreas, liver and breast cancer in animals. DBP can also affect the reproductive system (Croner, 1999).

TDI has slight acute toxicity to aquatic organisms and high toxicity to birds. Long-term effects includes slight toxicity to aquatic organisms. Diphenyl methane di-isocyanate has a lower toxicity than TDI.

Once cured, PU grouts are almost inert to water and do not release significant quantities of contaminants into the water. Whilst curing, there can be a significant loss of organic material to water. Tests on PU grouts have shown that total organic carbon (TOC) increases rapidly within 24 hours of injection, before decreasing again. The release of TOC related to 1 kg of polyurethane foam increases for up to 72 hours after injection before decreasing. Other changes include the appearance of yellowish discolouration, turbidity and a distinguishable musty smell. Again, these have almost disappeared by day three. Fish tests performed using the discharges found no ill effects. Provided, therefore, that the grout cures correctly there should be no additional environmental effects from the use of PU grouts as an alternative to acrylamide and/or NMA grouts.

Dibasic esters are readily biodegradable and also have low toxicity. Hence, the environmental risks from silicates may be lower than those from acrylamide and/or NMA grouts, although there may be considerable uncertainty caused by the actual composition of the grouts.

Health Effects

One of the main constraints on applying risk reduction measures is the potential health risks that may be introduced by the use of alternatives. This is particularly important for polyurethane grouts (the main alternative to acrylamide grouts for sewer repairs) based on di-isocyanates. TDI is classified as having high toxicity and being a severe irritant and respiratory sensitiser with possible long-term effects. Diphenylmethane di-isocyanate (MDI) is classified as being harmful, having moderate toxicity and is a severe irritant and respiratory sensitiser (Croner, 1998).

A study following the use of polyurethane grouts in Belgium in which two workers died was unable to conclude that the death was as a direct result of exposure to MDI. The deaths may have been caused by the hypnotic effect of the solvents used as part of the grout (Tytgat *et al*, 1997).

Safety instructions given with a TDI-free polyurethane grout suggests that safety goggles, gloves and safety clothing must be worn at all times and a face shield is highly recommended in case of spills or packer blow-outs.

Consultation has also indicated that the risks associated with polyurethane grouts are highly dependent upon the type used. There is also a serious risk of fire associated with their use. However, a direct comparison of the risks between acrylamide and/or NMA grouts and polyurethane grouts may not be strictly valid since the method of application (for sewer repairs) is different. Acrylamide grouts are often applied by pumping the grout into the pipeline which may require larger amounts of grout than would be used when applying polyurethane between packers. This also means that the polyurethane grouts (and any risks from them) are more localised.

In the construction industry, the main alternative to acrylamide and NMA grouts are the silicates and formaldehydes. Silicate grouts are non-toxic (although there may be some concern over silicate in dust form). They use dibasic esters as hardener. The human health effects of contact with these chemicals are:

- skin contact may cause irritation with discomfort or a rash;
- eye contact may cause eye irritation with discomfort, tearing or blurring of vision;
- inhalation may cause irritation of the upper respiratory passages, with coughing and discomfort;
- individuals who may be over-exposed may suffer blurry vision; and
- dibasic esters are not classified as carcinogens (DuPont, 1999).

Silicate grouts are also non-flammable and do not emit toxic gases following heating.

The use of formaldehyde grouts is now very low due to the greater availability and lower price of the silicate grouts. Resins containing formaldehyde can cause skin and membrane irritation, with the potential to cause eczema (Yrkeshygienisk Institutt, 1982). Formaldehyde is also considered a suspected carcinogen.

Cementitious grouts would tend to be used in combination with acrylamide and NMA grouts (or their alternatives) rather than acting as direct substitutes.

Costs

The relative costs of the different types of grouts for both tunnelling and sewer repairs is provided in Table 2.5.

Table 2.5: Comparative Costs for Different Grout Types			
Grout Type	Tunnelling¹	Sewer Repairs²	
	£/m³ (€/m³)	£/m² (€/m²)	effectiveness
Acrylamide	1,900 (3,000)	70 - 160 ⁴ (110 - 260)	100%
Acrylic	1,900 (3,000)		
Acrylate	4,600 ³ (7,400)		
Polyurethane	1,900 (3,000)		
Epoxy	no data	500 (800)	95%
Silicates	500 - 1,200 (800 - 1,900)	70 - 200 (110 - 320)	100%
Formaldehyde	no data	no data	
Cement-based	100 - 130 (160 - 210)	400 (640)	95%
Microcement	290 - 750 (460 - 1,200)		
Bentonite-based	no data	no data	
Source: ¹ consultation ² Jones M (1998): Sewer Leakage - Detection and Cures ³ costs extrapolated using Lisk I (Ed.) (1997): How to Plan a Chemical Grout Program , article downloaded from the Hydrocarbon Online Internet Site (http://www.hydrocarbon-online/) ⁴ costs given for 'chemical grouts' only Notes: all costs are given to two significant figures			

2.4.4 Comparative Risk Implications

Consultation and a review of literature has indicated that, although there is a wide range of grouts which could be used as substitutes for acrylamide and NMA grouts, the main alternatives would be:

- polyurethanes (particularly water-reactive polyurethanes) for use in sewer and manhole repairs; and
- cements, microcements and silicates for use in the construction industry (including tunnels, dams, soil stabilisation, etc.).

Environmental risks for all grouts (including acrylamide and NMA) are generally limited to times when the grout does not cure correctly. Given the wide range of potential compositions of any one grout, it is not possible to provide a quantitative indication as to which grouts will have lower environmental impact. However, some general observations can be made.

PU grouts comprise a large number of chemical constituents some of which pose potentially higher risk to the environment than acrylamide and NMA grouts. However, the precise composition of PU grouts varies widely and the relative environmental risks may also be lower. The use of polyurethane grouts may also introduce health risks which may increase the risks faced by workers (particularly for small-scale uses).

Silicates and cements are generally considered to be inert. However, some silicate grouts contain dibasic esters which may be more toxic than acrylamide to certain fish species. Cements and silicates in uncured form also pose environmental risk due to the potential for smothering and/or due to high alkalinity. Silicate grouts do not introduce any significant additional human health risks, although there is some concern that silicate dust may cause cancer. However, most silicate grouts are provided in liquid form, hence, this should not be an issue. Silicate grouts can be used to replace polyurethane grouts and do not require respirators or self-contained breathing apparatus to be used. There are also some health risks associated with the ester hardeners (DBE), but again these are less than acrylamide/NMA and polyurethane grouts.

Methylmethacrylate grouts are assumed (within the grouting industry) to be non-toxic although toxicity to certain fish species is comparable to that of acrylamide. Acrylate grouts are reported to have a much lower toxicity than acrylamide and/or NMA grouts (up to 1/100 less).

3. CURRENT USE AND RISK REDUCTION MEASURES

3.1 Use of Acrylamide Grouts

Consultation has also failed to locate any users of acrylamide grouts within the EU due mainly to increased awareness of the environmental and health problems that may be caused. However, one company has stated that they would prescribe the use of acrylamide grouts but only if the conditions were correct⁵. These conditions, however, are very specialised and it is unlikely that large quantities of the grout would be required. More commonly, the grout would be used in combination with other types of grout, such as silicates.

The market share for acrylamide grouts, therefore, is likely to be very small. Indeed, a Japanese company has confirmed that it does not supply acrylamide for use in grouts in either the UK or Europe. It is unlikely that the market share would ever become significant given the bad publicity surrounding the use of these grouts and the fears over environmental and health risks.

Acrylamide grouts have, however, been used in Europe over the past 30 years following the development of AM-9 by Cyanamid. AM-9 was an acrylamide grout for use as a rapid setting grout in sewer sealing. It had a very low viscosity (similar to that of water at 1 to 2 centipoise) which meant that it could be used in a wide range of applications. The setting time could also be changed to suit almost any situation. AM-9, like all acrylamide grouts, had a high water content (50% to 80%) which means that the gel that is formed is weak and may be susceptible to erosion out of the ground.

The grout had worldwide application, with large volumes being used in combination with formaldehyde in Belgium and France. Use continued until 1977/78 when Cyanamid ceased production after workers in Japan were poisoned whilst using the grout in a tunnel linking the two islands. However, the grout was used in flowing water which diluted the acrylamide content to below 10%. The grout, therefore, would not set.

Studies undertaken in the UK and elsewhere had already highlighted the potential health problems following use of acrylamide grouts⁶ and a move away from acrylamide grouts had already begun.

Acrylamide grouts are still used extensively in the United States, however, in particular for sewer repairs. The grouts are particularly useful for this application because of their very rapid setting time. They are imported in both liquid and powder form from South America and Japan, respectively before being supplied to sewer repair companies. In 1989, about 300,000 kilograms of acrylamide grout were used (making up approximately

⁵ Under conditions of no flowing water, for the sealing of isolated wet spots or where no other product would permeate.

⁶ In particular, chronic effects on the central nervous system and potential carcinogenicity.

43% of total chemical grout usage in the US). Of this, about 260,000 kg was used in sewer repairs (US EPA (1991a)).

An examination of environmental and human health risks from the use of acrylamide and NMA grouts resulted in a proposal by the US EPA for a ban in 1991 (US EPA, 1991a). NMA was later removed due to a lack of suitable alternatives. On-going discussions between the sewer repair industry and the US EPA indicate that to avoid a ban on acrylamide grouts, the supplying company would be willing to cease imports of the powder form of acrylamide. The implications of this decision for risk reduction measures that could be imposed within the EU is discussed further in Section 4⁷.

Small volumes of acrylamide may also be used in micro-tunnelling, in the drilling fluids used as lubricants. The drilling fluids contain between 40% and 98% polymer, where this consists of an acrylamide/sodium acrylate copolymer. Typically, five gallons of the concentrated drilling fluid would yield 3,000 to 5,000 gallons of mud. Hence, the final concentration of acrylamide would be very low. The lubricants are classified as safe for use in water wells and as harmless to the environment.

The drilling muds can be used for most drilling operations in all fine soils and rock formations, including clayey soils⁸.

3.2 Use of NMA-Based Grouts

The use of the term NMA-based grouts is actually a misnomer since the grouts are not based on NMA. Indeed, NMA often forms only a very minor percentage (usually 2% to 3%) of the overall composition of the grout and these grouts are usually grouped under the heading of acrylic grouts⁹. NMA is usually found within the accelerator component of these grouts.

Rhoca-Gil included both NMA and acrylamide, with an acrylamide content of between 1.5% and 4.2% (Anon, 1997). Production of this grout was stopped in 1997 following the incidents at Hallandsås and Romeriksporten. Before this, however, it was widely used despite fears that it was not very safe for workers. Countries such as the Netherlands, Belgium and France used it extensively in a wide range of applications. One Belgian grouting company continued to use the grout until production was stopped. In Norway, Rhoca-Gil (also called Siprogel) was used between 1981 and 1997 to seal tunnels, dams, bridges and to strengthen ground (Aftenposten, 1997a).

⁷ The US EPA have since decided to propose a ban on acrylamide grouts. This is currently under internal review at the US EPA. It is anticipated that the rule will be promulgated as it is currently drafted.

⁸ Articles downloaded from (<http://www.microtunneling.com/les>).

⁹ Acrylic is a generic term used to include strong gels and may also include acrylates. The actual definition and types of grouts that are included differs between producers, suppliers and users and can be the cause of significant confusion.

Sales of Rhoca-Gil were worth a few hundred thousand pounds a year to Rhone-Poulenc, indicating that the market share for this type of grout was quite small (Aftenposten, 1997b). Consultation indicates that there may be at least two companies currently supplying grouts containing NMA, but that the use of these grouts is restricted to very specialised conditions, which may be encountered only 1% of the time. One of these companies may be importing grouts containing NMA into the EU but the market share is likely to be even less than that occupied by Rhoca-Gil.

Since the incident at Romeriksporten, the main user of chemical based grouts, the Norwegian Public Roads Administration has switched to pure Portland cement based grouts. These have worked successfully despite unfavourable work conditions.

A grout containing NMA (or an alkaline derivative of it) has been identified for use in the Copenhagen Metro Project, Denmark for use in emergency grouting. This grout is a three-component type, with the NMA present in the accelerator component. Stringent conditions for the use of this grout have been laid down by the local authority (these are discussed further below).

Acrylamide and NMA grouts have been used occasionally in Spain over the last ten years, mainly for waterproofing tunnels but also for consolidating mines. They have now switched to alternatives, particularly microcements.

NMA grouts are also used in the United States for sewer repairs, currently making up about 3% of the total chemical grouting market (Environment Agency, 1999). They would form the main alternative to acrylamide grouts if acrylamide grouts were banned by the US EPA.

3.3 Current Risk Reduction Measures

There are few formal government guidelines or restrictions on the use of grouts in most EU countries (including the UK). However, Germany restricts the types of chemical that can be injected into the ground, where these are mainly on organic compounds. The EC Framework Directive on Water Resources may also result in some control. Earlier drafts were of concern to grouting companies since they included significant restrictions on the type of chemicals that could be injected into the ground; these have now been relaxed slightly.

At an industry level, the risk reduction measures currently in place are linked to the need to produce a Method Statement, where the companies proposing the use of a particular grout must effectively justify their choice by including all of the technical and health and safety information supplied by the manufacturer. This type of approach has been used for the past fifteen years in the UK. The contractors are then aware of the types of precautions that need to be taken and protective clothing that should be worn.

The safety instructions given with Rhoca-Gil, for example, state that respirators are required together with close-fitting safety glasses. Safety clothes and plastic aprons with safety gloves of a resistant material should be used to protect the skin. In addition, the

user should not dispose of the substance to sewer, rivers, streams or other watercourses (Aftenposten, 1997c).

Some grouts are supplied in pre-packaged form and, hence, can be used by those with less experience (often smaller firms). Such firms may not always be aware of the necessary precautions or of the history associated with the use of particular types of grout. It is this type of user who may pose the greatest risk of mis-application, although they would have all of the relevant technical and safety data sheets if they requested them from the manufacturer.

Current risk reduction measures may also include detailed conditions under which these grouts may be used. As indicated above, a grout containing an alkaline deriviate of NMA may be used in the Copenhagen Metro Project in Denmark but this will be subject to very stringent conditions as laid down by the local authority. These are that:

- the grout may only be used where no water supply interests exist;
- the contractor must separate and collect water and soil/rock that may come into contact with the grout during the grouting operation. This collected material must then be analysed and, if contaminated, it must be disposed of in accordance with statutory regulations;
- the grout may only be used within the New Austrian Tunnelling Method¹⁰ (NATM) tunnels; and
- the grout must be used in accordance with the Contractor's submitted documentation.

In addition, Norway has approached the European Commission with proposals for national marketing and use restrictions on grouts containing acrylamide. The Directorate for Environmental Defence (Miljøverndepartementet) has now introduced a ban on the use of acrylamide grouts in the construction industry. However, the State Pollution Control Authority (Statens Forurensningstilsyn, SFT) can consult with the Directorate for Labour Conditions (Arbeidsmiljømyndighetene) to give permission for the use of grouts containing acrylamide to prevent serious health and environmental risks from the use of alternative grouts¹¹.

¹⁰ This method uses an initial lining of shotcrete, steel arches and/or rockbolts either singly or in combination plus a waterproof lining to protect the inner lining against ingress of water (from Sauer G (1988): *Further Insights into the NATM*, extracts from a paper given at the Tunnelling '88 conference, London, downloaded from (http://www.dr/sauer.com/natm/f_ins.htm)).

¹¹ Press release dated 23.12.99 downloaded from Offentlig Dokumentasjon og Informasjon i Norge Internet (ODIN) site (<http://odin.dep.no/html/nofovalt/pr-meld/md/1999/k4/991223.html>). Translations of Norwegian Government Departments provided.

3.4 Comparison of the US and EU Markets

As noted above, the use of grouts containing acrylamide and/or NMA is much larger in the United States. An estimate of the potential market size could be \$6.5 million (or £4.1 million, €6.6 million)². The market share for acrylamide and NMA grouts is estimated as 50%, or \$3.3 million (£2.1 million, €3.4 million). However, it is likely that the overall market for chemical grouts is much smaller in the EU (and in the UK in particular) than it is in the US. Sales of Rhoca-Gil indicate that the maximum value of the market in the EU in grouts containing NMA is a few hundred thousand pounds, and is probably less than this.

The relevant market shares of the different types of grout are also likely to vary. This is mainly because of the very strong lobby that exists in the United States for the continued use of acrylamide and NMA grouts. There has not been the same amount of lobbying in Europe and, hence, the market share of these grouts is now very small.

As previously discussed, the main market for acrylamide and NMA grouts in the US is the sewer repair industry. The type of approaches used to repair sewers in the US also tend to be different from those used in Europe. Again, therefore, the market for chemical grouts overall is much smaller than in the US.

¹² Assuming sales of around 400 tonnes of acrylamide grout and comparing this with relative costs and volumes sold of the alternatives. Also assuming that there are 1.6 US dollars to £1.

4. THE PROPOSED RISK REDUCTION MEASURES

4.1 Overview

Chemical grouts tend to be used on a site-by-site basis often being viewed as more of an art than a science. There is no publication trail to ensure that information on the effectiveness and health risks is passed on. In combination with the rapid turnover of staff in engineering firms, there is not a continuous improvement in knowledge about the risks from the various types of grout. This is illustrated by the generation gap between the introduction of various types of chemical grout and the problems that have recently occurred.

The incidents at Hallandsås, Sweden and Romeriksporten, Norway show that there is a need for some kind of control on the use of acrylamide or NMA grouts to reduce the risk of further such events. Clearly, the risk reduction measures must offer the potential for mitigating risks caused by mis-application, since it is under these conditions that the major problems have occurred.

The possible risk reduction measures that have been identified as being the most relevant are:

- marketing and use restrictions;
- voluntary schemes (a certification system or specifying conditions for use);
- restrictions on the chemical form of the grouts; and
- changes to the Material Safety Data Sheets and/or Labelling System.

4.2 Marketing and Use Restrictions

Under Directive 76/769/EEC, the marketing and use restrictions that may be appropriate for grouts containing acrylamide and/or NMA could include:

- banning the use of grouts containing acrylamide and/or NMA which would eliminate all risks to the environment and worker health including those associated with mis-application of the grouts;
- derogating specified uses, for example, for specialist construction uses on a small-scale where environmental risks are assumed to be negligible;
- phasing in restrictions to allow companies currently using the grouts to find alternatives; or
- restricting the concentration of NMA in grout preparations; this is not considered appropriate for acrylamide grouts since it may reduce the potential for polymerisation and could, therefore, increase the risks.

4.3 Voluntary Schemes

4.3.1 Introduction

There are three categories of voluntary instrument and three types of environmental agreement:

- voluntary agreements:
 - ▶ public voluntary programmes;
 - ▶ negotiated agreements; and
 - ▶ unilateral non-binding commitments.
- environmental agreements:
 - ▶ national environmental agreements;
 - ▶ environmental agreements implementing certain provisions of EC-Directives; and
 - ▶ Community environmental agreements.

However, unilateral non-binding agreements are currently the only instruments available to the European Commission. The agreements would be recognised in a Recommendation published in the Official Journal, although the Commission would not be a direct party to them.

Agreements and progress should be published publically (e.g. through Directive 90/313/EEC on the freedom of access to information on the environment). This will ensure transparency and should improve both the perception of the agreement's effectiveness compared with purely legislative action and the environmental credentials of the companies party to the agreement.

The following sections describe two potential risk reduction measures based on voluntary schemes.

4.3.2 Certification System

A certification system could be used to ensure that all users of acrylamide and NMA grouts have undertaken appropriate training, are sufficiently aware of the risks associated with the grouts and can determine which uses would (and would not) be appropriate.

There are three potential ways of supervising a certification scheme:

1. The scheme could be operated and controlled by a Government body (or other body with regulatory powers). This body would be responsible for ensuring that the certificates are only issued to those users who have completed the appropriate training, etc. They would also be responsible for monitoring use of the grouts;
2. The scheme could be operated in such a way that suppliers can only sell to certified users. A body with regulatory powers would issue the certificates, but the degree of monitoring required would be reduced if all suppliers are required

to report all sales of acrylamide and NMA grouts and the company to whom they are supplying to the regulator; or

3. The scheme could be overseen jointly by a trade association(s) and the supplying companies who would be responsible for ensuring that the companies that use the grouts are sufficiently competent to do so. This option is similar in many ways to a voluntary agreement as it requires industry to take steps towards ensuring that such a scheme is set up, implemented and would work.

Certificates could also be issued in relation to certain grouts, allowing them to be used under specified conditions. Such systems would need to include technical support from the suppliers to ensure that the conditions of use were clearly understood by the user and that there was no potential for different interpretation.

The form of the certification system would be such that it could be considered as an economic instrument, or a type of tax on acrylamide and NMA grouts due to the extra costs involved in setting up, running and monitoring the scheme. The extent to which any part of the industry (producers, suppliers, users, etc.) would be involved would depend on the chosen form of the certification system.

4.3.3 Conditions for Use

Specifying conditions for use (such as those laid down for the Copenhagen Metro Project) could be extended so that it is a requirement of all projects where grouts containing acrylamide and/or NMA are to be used. Additional conditions may also be required according to the geology/hydrogeology of the area and could include:

- a maximum flow or leakage rate above which the grouts could not be applied (to reduce the risk of dilution); or
- a temperature range outside of which the grouts could not be used.

The most effective way of implementing this type of approach would be to build upon the steps currently taken by grouting contractors when compiling Method Statements. These statements should include all of the relevant information on potential health and environmental effects and could be used by the authority responsible for the project as a whole as the basis for specifying the conditions of use. This would involve a unilateral non-binding agreement with the grouting industry as a whole (manufacturers, distributors and contractors) with a degree of local control under, for example, the local authority or government. In many cases, this will be equivalent to an increase in the role of the supervisory bodies. Conditions would be specified before any grouting work commenced.

The problem of ensuring a consistent approach throughout the EU may be reduced as a result of the organisation of the grouting industry. This is dominated by a small number of international firms (manufacturers, distributors and contractors) which should minimise differences between Member States. Site specific factors such as local geology

and hydrogeology will mean, in any case, that specified conditions for use could not be set at a higher level. Therefore, local authorities should be in a position to make the best informed decisions as to which conditions are necessary within their jurisdiction. The specified conditions for use could then be tailored to take into account who and what needs to be protected and how this could be achieved most efficiently.

To aid local authorities with this task, it may be necessary to provide guidance on how this has and/or is currently being achieved. Details of example schemes, such as that followed on the Copenhagen Metro Project and/or checklists of factors that need to be considered, could be made available to aid with decision making. Other pre-existing schemes and codes, such as the Code of Conduct on Chemicals Subject to Trade Controls or Voluntary Agreements (CIA, 1995), could be used to ensure internal monitoring of the proposals by industry.

Each set of conditions would, in effect, form a separate environmental agreement where the parties would be the firms using the grouts and the supervisory bodies. The supervisory bodies would be responsible for identifying the obligations of each of the parties, with industry assisting by supplying all of the relevant information. This information would need to be continually updated as more projects are completed and as grouting methods evolve. There would be no need to join the agreement as such, since all grouting contractors would become party to the agreement once they become involved in a project.

4.4 Restrictions on the Chemical Form of the Grouts

The National Association of Sewer Service Companies (NASSCO) in the United States set out in a letter to the US EPA their proposals for a Significant New Use Rule (SNUR) to reduce the risks from acrylamide grouts and avoid the promulgation of a ban. These are:

- the supplier of acrylamide grouts in the US would enter into a voluntary agreement with the US EPA to cease importation of acrylamide grout in powder form. All of its customers would then be required to use all existing stocks of the powder form by an agreed date;
- the supplier would then sell only the liquid form of the grout and then only if purchasers agreed to specified conditions concerning its use;
- all NASSCO members would agree to use existing stocks of the powder form of the grout by an agreed date and to use the liquid form in accordance with the conditions for use as set out by the supplier; where
- the conditions for use would include: use of specified application equipment; completion of an appropriate training course covering proper application of the

grout and use of personal protection equipment; and continual update and use of a training manual.

The use of liquid forms of acrylamide grouts is associated with much lower worker health risks than the use of the powder form. However, the use of acrylamide grouts in general within the EU is very small and a restriction of this type is unlikely to have a significant effect on risks. The US EPA has also agreed to remove NMA grouts from the proposed ban so they are not considered within these risk reduction measures. It is not clear as to how NMA grouts could be included within measures of this type.

Specifying the level of training required, the use of proper equipment and use of a continually updated training manual is considered to have been covered under the certification system. This risk reduction measure is not, therefore, considered further.

4.5 Changes to the Material Safety Data Sheets and/or Labelling System

One of the major problems in the Swedish and Norwegian examples was that the manufacturer of Rhoca-Gil provided inadequate information as to the contents of the grout and the concentration of acrylamide that it contained. In Norway, for example, the contractors were not aware that Rhoca-Gil contained acrylamide¹³.

This suggests that a change to the information that technical and material safety data sheets (MSDS) contain may reduce the risks associated with the grouts. The current system requires the composition (nature of the ingredients and their concentration) and information on ingredients to be given¹⁴. However, for a preparation it is not necessary to give the full composition. Substances that need not be indicated are those with concentrations by weight which are less than:

- 0.1% for substances classified as toxic or very toxic¹⁵;
- 1% for substances classified as harmful, corrosive or irritant; or
- unless lower limits have been set in Annex 1 to Directive 67/548/EEC¹⁶.

¹³ However, a report by Yrkeshygienisk Instituttt (1982) which compares some of the health risks of chemical grouts includes Rhoca-Gil (and Siprogel) as containing an acrylamide derivative. Similarly, an article by Stormark (1998) suggests that the contractors had included details of their intention to use a grout based on acrylamide in documentation dated 1994.

¹⁴ Directive 91/155/EEC concerning Material Safety Data Sheets for Hazardous Substances and Preparations.

¹⁵ Acrylamide is classified as toxic in contact with skin and if swallowed.

¹⁶ Directive 88/379/EEC on the approximation of the laws, regulations and administrative provisions of the Member States relating to the classification, packaging and labelling of dangerous preparations.

The MSDS should, therefore, include acrylamide wherever its concentration exceeds 0.1%. The concentration of acrylamide in Rhoca-Gil was between 1.5% to 4.2% (Anon, 1997) and should, therefore, have been included in the information that was provided. There may, therefore, be a need for users to be able to demand that information provided to them is checked rather than a change to the method of production of safety data sheets.

NMA should be included on MSDS when it exceeds 1%. The MSDS for an NMA grout supplied in the United States does include NMA as it makes up 38% of the total composition of the grout. Consultation has indicated that in the EU, the percentage of NMA within these grouts is much less and so may not always be included. This is a cause of considerable confusion as to which grouts contain NMA and which do not.

5. AN ASSESSMENT OF THE RISK REDUCTION MEASURES

5.1 Overview

This Section assesses each of the risk reduction measures described in Section 4 by considering their effectiveness, practicality, economic impact and monitorability as given in the *Technical Guidance Document on Development of Risk Reduction Strategies* (October, 1997). Where available, an estimate of the costs associated with each of the proposals is also given.

5.2 Marketing and Use Restrictions

Effectiveness

Banning the use of grouts containing acrylamide and/or NMA would ensure that all of the environmental (and human health) risks associated with both normal use and mis-application would be eliminated. Phasing in the restrictions would clearly be less effective during the phasing-in period, hence the timescale for reductions of the risks would be longer.

In considering the appropriateness of this measure, it must be remembered that these grouts are currently used in approximately 1% of construction situations, where the alternatives are too viscous or contain too many particles to allow the grout to penetrate into all the same voids and cracks as water can enter. In addition, data on the environmental risks associated with the alternatives suggests that the toxicity of the different chemicals that may be present in alternative grout formulations may not always be lower. The actual toxicity will depend upon the percentage that each chemical comprises in the final grout (and which can be highly variable even between similar grouts) and the conditions of release. Hence, a ban on acrylamide and NMA grouts may reduce the risks, may increase the risks or may result in different risks. An actual comparison of risks could not be carried out without considering each grout in greater detail, and such an analysis would still be subject to considerable uncertainty. Hence, the overall potential for the reduction of risks is unclear, making the effect of marketing and use restrictions uncertain.

Similarly, derogations for particular uses, such as small-scale sewer repairs, would not increase the risks above a negligible level and may, where the risks of the alternatives are of a similar magnitude, have no real effect on the overall risks to the environment and human health.

Practicality

The implementation of marketing and use restrictions would require an amendment to Directive 76/769/EEC. A ban is likely to encourage a move to the alternative grouts, particularly silicates and polyurethanes. Consultation has indicated that these alternatives are already used in the majority of applications but that they may not be suitable in the

specialised conditions faced 1% of the time. Hence, a ban may encourage the use of potentially unsuitable grouts in these specialised circumstances. This may increase the chance of mis-application of the alternatives and cause additional risks (although, again, uncertainty associated with the level and types of risk is high).

Economic Impact

Consultation has not identified any current users of acrylamide grouts within the EU, hence, there should be negligible economic impact. There may be some importation of these grouts and they may be used from time to time due to the lack of on-going knowledge within the grouting and engineering industries. However, it is unlikely that a ban would have any significant effect on this somewhat erratic potential use.

Impacts on producers and suppliers of NMA grouts may be greater, although the maximum size of the market is estimated at £500,000 (€800,000). Impacts following marketing and use restrictions may be placed on contractors who would have used acrylamide and/or NMA grouts in the 1% of specialised situations. Unless there is a substitute which is as effective under these conditions (the potential for this will be determined by the site conditions and the experience of the contractors in using chemical grouts), there may be cost implications for the project. These costs may include increased pumping costs if the ground cannot be adequately sealed (such leaks may also affect the lifespan of the construction unless adequately controlled), fines as a result of not meeting pre-set requirements (for example, water leakage rates or to reduce movement of buildings under which tunnels are being dug) or delays in project completion.

The US EPA estimated costs of a ban on acrylamide and NMA grouts would be \$8.8 to \$18.3 million per year (£5.5 to £11.4 million; €8.8 to €18.2 million), reducing to \$6.5 to \$13.3 million per year (£4 to £8.3 million; €6.5 to €13.3 million) if there was a three-year delay in banning NMA grouts. This assumes a move to an alternative chemical grout (US EPA, 1991b).

An estimate of the costs within the EU can be made by considering that sales of Rhoca Gil amounted to an estimated £500,000 (€800,000) per year (Herbjørnsrud, 1997). The additional costs of moving to polyurethane grouts are £5 million or €8 million (using the US EPA figure of \$16.11 incremental \$/mixed gallon of NMA grout; equivalent to £10 or €16¹⁷). However, this value is likely to be an over-estimate as many previous users of Rhoca Gil have now moved away from acrylamide and NMA grouts. This includes, for example, Spain and Norway, both of whom have switched to cement-based grouts.

Silicate, cement and microcement-based grouts are less expensive than acrylamide and NMA grouts. However, there may be additional equipment costs and these grouts may not always be 100% effective (see Table 2.3). Where these alternative grouts cannot provide a 100% effective alternative, there may be lost productivity during tunnel construction, additional pumping costs where water infiltration is excessive and, where

¹⁷ The US EPA figure is used in preference to the relative costs given in Table 2.5 since this includes costs associated with additional equipment and training requirements. Some worker productivity may also be lost when using certain types of polyurethane grouts (US EPA, 1991b).

there are concerns over the lowering of groundwater levels (as in Sweden and Norway), there may be considerable losses in conservation value and impacts on drinking water and irrigation supplies.

At Romeriksporten, the use of a 'successful' grout lowered the costs associated with the reduction in groundwater levels by NOK 100,000 to 200,000 (£7,800 to £16,000 or €12,000 to €26,000) between 1 January 1998 and 30 June 1998 and by NOK c.500,000 (£39,000 or €62,000) between 15 August 1998 and 15 November 1998 (NOU, 1999). This gives an indication of the types of costs (about £100,000 or €160,000 per year) that could be expected if grouting is not 100% effective at reducing leaks into tunnels.

Overall total costs associated with a ban on acrylamide and NMA grouts can be estimated at approximately £5 million (€8 million) per year from the move to alternative grouts plus potentially another £100,000 (€160,000) per year through lost effectiveness. As noted above, the former set of figures may be an over-estimate as it is based on usage at the times of the incidents at Hallandsås and Romeriksporten (October 1997) and consultation has indicated that there has been a move away from these grouts since this date. The costs associated with reduced pumping and treatment costs associated with lowering water levels will depend upon site specific characteristics, with £100,000 (€160,000) taken here as an indicative figure relating to a large railway tunnel in an area with numerous lakes and highly fractured rock. Total costs for grouting companies therefore, may amount to around £5.1 million per year (€8.2 million).

These costs can be compared to the potential benefits of avoiding incidents such as that at Hallandsås, where the total financial value of claims paid out was SEK 26 million (£1.9 million or €3 million). This excludes the environmental and ecological costs associated with the incident, however, and so underestimates the total damages caused. Assuming that losses in Norway were similar and ignoring the delay in achieving these benefits due to the timeframe required to introduce marketing and use restrictions, the costs would appear to outweigh the benefits and, hence, marketing and use restrictions are not justified.

Monitorability

In terms of monitoring any marketing and use restrictions, acrylamide grouts are readily identifiable because of their chemistry and the type of gel that they form. Hence, there should be no major difficulties in identifying these grouts. There may be greater problems in monitoring of grouts containing NMA mainly because of the confusion that exists within the industry as to which grouts contain NMA and which do not. This is because NMA can make up such a small concentration of the total preparation. Some effort may be required to clarify this issue and to ensure that all grouts containing NMA are included within the marketing and use restrictions.

Following introduction of a ban, monitoring would only be required on imports to ensure that these grouts were not brought into the EU. This should be relatively straightforward for acrylamide grouts but, again, may be more difficult for grouts containing NMA given the potential that it may not always have to be listed in technical information.

5.3 Voluntary Schemes

5.3.1 Introduction

The European Commission requires three key elements for voluntary and environmental agreements:

- efficiency;
- transparency; and
- credibility.

The European Commission also provides a checklist to environmental agreements, which covers reasons for the choice of the instrument, content, compliance with EC Treaty and Publication (European Commission, 1996).

Therefore, the proposed measures will also be considered against the criteria set out by the European Commission in the checklist for environmental agreements (European Commission, 1996). Factors identified by the European Environment Agency (EEA, 1997) as requirements for successful environmental agreements will also be discussed.

5.3.2 Certification System

Effectiveness

The effectiveness of any certification scheme will be determined by its operation and control. It may be particularly useful for grouts containing NMA, although it would be necessary to obtain complete information from the manufacturers. Ensuring that the grouts could only be used by certified users should reduce the potential for mis-application (and hence the environmental and human health risks associated with incorrect usage), providing that certificates are only given to those with sufficient practical experience to be aware of the potential problems which may arise.

Under conditions of 'normal' use (i.e. those which should predominate when grouts containing acrylamide and NMA are used by those with sufficient training and experience), the environmental risks from the use of these grouts should be minimised.

The certification system may not reduce risks to workers on large-scale projects due mainly to the lack of a threshold value below which exposure is not considered to be hazardous. However, it should promote more careful usage of the grouts by increasing awareness and prevent problems such as those seen in Norway, where workers were not wearing respirators and many were not wearing sufficient protective clothing.

Practicality

Practicality will be determined by the commitment of the grouting industry as a whole to the development and continued operation of a certification system. Consultation has identified that it is not always possible to obtain information from the manufacturers as to the make-up of the grouts that they are producing. Clearly, more transparency would

be required for a certification system to work. However, the confidentiality of the actual composition of the grouts would have to be maintained to ensure that the commercial rights of the companies involved are not affected.

Almost the entire supply chain would need to be involved with the certification system due to the complex nature of the use of the products. Applying the certification system to specialist grouting companies only may not achieve the desired reduction in environmental (and human health) risks because they may only be applying the grout. Certification of those determining which grouts should be used may also be required. This makes the system much more difficult to organise since it requires the commitment of a larger number of companies, trade associations, etc.

Economic Impact

It is likely that the introduction of a certification system would involve considerable expense to those requiring authorisation to use acrylamide and/or NMA grouts. There may also be significant financial costs in setting up and monitoring the scheme. In effect, the economic impact may be such that the grouts become too expensive to use (effectively being banned). This approach may also provide an incentive to undertake research and development into new alternative grouts that would be as effective as acrylamide and/or NMA grouts.

Costs of implementing also may fall disproportionately on small and medium enterprises (SMEs) since these companies would have to undertake the same level of training for all employees in order to qualify for certificates.

Under conditions where the grouts become too expensive to use, issues concerning the use of unsuitable alternatives is again raised. Mis-application of the alternative grouts (particularly polyurethanes) may have equally serious impacts on the environment to the mis-use of grouts containing acrylamide and/or NMA.

Should the costs of the certification system be sufficient that they encourage use of alternative grouts which are not able to seal the finest cracks, there may be significant lowering of groundwater tables following tunnel construction (although the geology and hydrogeology of a region will be similar constraints to this). The costs of pumping and treating this water could amount to £100,000 per year (€160,000) (based on figures given in NOU, 1999).

Overall, consultation has indicated that the costs of such a scheme may be prohibitive, although no cost estimates have been made.

Monitorability

Monitoring of the scheme would be critical to ensuring its success. Monitoring is likely to be required at two levels: the user level and the supplier level to ensure that there are no loopholes within the system. Of particular difficulty will be ensuring that all staff using the acrylamide and NMA grouts are suitably trained and have the most up-to-date

information (given the rapid turnover of personnel in this area), as well as ensuring that the information provided by the manufacturers and suppliers of grouts is correct.

Suitability as an Environmental Agreement

A certification scheme is more efficient and cost-effective than a ban because it allows continued use of acrylamide and NMA grouts where there are no effective alternatives but, by increasing the costs of so doing, it encourages research into possible new alternatives. As acrylamide and NMA grouts can continue to be used whilst new, and safer, alternatives are found, there is less pressure to use less effective grouts. The use of less effective grouts has the potential to increase other costs (e.g. pumping costs) and may, if the alternative grout is unable to cure correctly, increase the risks. Therefore, there are possible environmental benefits to this scheme compared to legislative measures.

Sector coverage will depend upon the form of the certification scheme, but should be comprehensive where there are checks made by the issuers of certificates to assess the competence of users of the grouts.

Many suppliers of grouts already only sell their products to companies that they believe are sufficiently competent to use them correctly. Therefore, there is an informal approach between certain suppliers and users currently in place. The certification scheme will formalise this approach and make it more transparent.

The certification scheme is compliant with the EC Treaty since it will not significantly affect the free movement of goods or affect competition. The only competitors who may be affected would be those who either were not sufficiently experienced/trained to qualify for certificates or those who could not afford the extra costs of training staff to the required level. However, since most work with acrylamide and NMA grouts is undertaken by specialist companies, there are not expected to be many (if any) companies falling into the latter category. In any case, any company wishing to join the scheme could do so by providing data to support their claim that they are sufficiently experienced and trained to use acrylamide and NMA grouts.

Consideration of the factors identified by the European Environment Agency (EEA, 1997) shows that:

- the number of companies involved will depend upon the final form of the certification system. This could be large if certificates are required by all potential users or small if placed on suppliers of these grouts;
- acrylamide and NMA grouts are currently used in only 1% of situations, therefore, the market is considered to be mature. Competition, however, may be high and there may be the potential for free-riders (particularly if the chemistry of NMA grouts is not made more transparent);
- there is a limited number of sources of pollution but the environmental problems may be serious at a local level;

- the certification system sets targets related to the required level of training and experience and it should be straightforward to make these very clear;
- the technical solution is related to the expertise of the potential users;
- the costs, however, of complying with the environmental agreements may be high and may also be larger, particularly for small companies who would have to ensure the same level of training and expertise as larger companies to qualify for the certification scheme; and
- design and application of the scheme could be undertaken either by third parties or by industry itself.

5.3.3 Specified Conditions for Use

Effectiveness

The stipulation of very stringent conditions for use should reduce the potential risks to the environment (and to workers) providing the conditions given are suitable. The risks would be reduced because the potential for mis-application is reduced, as would be the potential for a contractor to have already begun using large quantities of a grout before informing the authorities (as in Sweden). Any conditions must be closely supervised with good communication between all parties involved. Sweden, for example, has very strict laws on the need for environmental impact assessments and worker health, but this did not provide details of alternative measures that may have resulted in lower environmental risks or prevent the problems experienced by workers at Hallandsås. It would also be necessary that the authority setting the conditions has full access to all information on the grouts that were to be used and that this information was correct.

Risks to the environment should be reduced following the introduction of this type of risk reduction measure since the potential for mis-application should be considerably reduced. Tests on other grouts have shown that the environmental risks from chemical grouts are limited to the time for complete curing, hence, once a grout has cured, the risks are generally negligible. The introduction of specified conditions for use should also increase awareness of the risks involved with using grouts containing acrylamide and NMA. Risks to worker health may not be affected unless the conditions for use contain additional safety requirements; although the increased awareness of the risks associated with the grouts should ensure that additional precautions are taken without the need for detailed instructions laid down by supervisory bodies¹⁸.

The use of specified conditions would rely on a voluntary industry commitment under the direction of local supervisory bodies. This may mean that different supervisory bodies can propose different sets of conditions which may lead to inconsistency between

¹⁸ The risk reduction strategy for human health (particularly workers) is currently being undertaken by the Health and Safety Executive (HSE). This report is not intended to present risk reduction measures specific to human health risks.

Member States. However, the nature of grouting work is such that the geological and hydrogeological conditions are likely to vary widely from site-to-site meaning that the conditions must also vary, even to provide similar levels of protection to drinking water, for example. The key measure here will not, therefore, be a consistent set of conditions but the assurance that incidents which could result in environmental impacts would be prevented. In this case, the most appropriate way to ensure this is to allow local supervisory bodies to set appropriate conditions (taking advice as necessary from producers and trade associations). Consistency can be assisted by the grouting contractors, for example, providing the supervisory bodies with Method Statements (or similar documentation) which sets out all of the reasons behind the choice of a particular chemical grout plus all of the associated environmental risks. Industry could also set up an information centre from which relevant details (conditions used in other locations, lists of factors to be considered when drawing up the conditions, etc.) could be easily obtained. Dissemination of information in this way will assist all of the parties involved with ensuring that the specified conditions will be suitably effective but still permit local knowledge and experience of site specific conditions to be incorporated.

Practicality

It is more practical to set conditions for use of the grouts than to apply the conditions to the grouts themselves. This is particularly true for grouts containing NMA when there may be a lack of information as to the exact contents of the grout. As noted earlier, stringent conditions are currently being applied in Denmark regarding grouting in the Copenhagen Metro project.

There may also be practical problems associated with different standards of conditions being adopted across Member States where, for example, one Member State (or appropriate supervisory body) sets only minimal conditions compared to those used in other Member States. Hence, the reduction in risk may not be consistent across the whole EU (as noted above). Furthermore, complex interactions between geology, hydrogeology, hydrology, physical conditions (temperature, pH, etc.), and the environment more generally may mean that the supervisory bodies developing the conditions for use would bear a large amount of responsibility in ensuring that the conditions specified are sufficient. Clearly, this may be a difficult task on large-scale projects where the geology (in particular) may not be very well known, for example, tunnels being dug through dolomitic rocks where the structure and soundness of the rock is not well known. Discovering there is sugar dolomite (a rock with the consistency of sugar) could require an alteration to the specified conditions. There may be a need, therefore, for a dynamic set of conditions which can be continually updated. This then creates uncertainty for the contractors and may make it difficult to plan a project far in advance. This illustrates the importance of a strong industry commitment and willingness to cooperate fully with supervisory bodies. Discussions should be ongoing throughout a project to prevent the specification of inflexible conditions or an unchangeable grouting plan.

Despite the potential disadvantages of using specified conditions for use, the fact that this approach is being taken in Denmark shows that it does have real potential as a method

for reducing the risks from the use of grouts containing NMA (or acrylamide). Furthermore, the latter suggests that the associated costs are not prohibitive.

Economic Impact

The costs will be associated with setting up the conditions and enforcing them. The actual impact will, therefore, vary between projects but should not have significant effect on the grouting companies unless they are required to invest in additional safety equipment, or to change their methods of working (or unless unexpected changes to the conditions are required). There will be some additional expense for local authorities (or other supervisory bodies) who would be required to draft conditions of use and who may bear the responsibility if problems occur.

Most countries do not currently have any guidelines in place that grouting contractors should follow although many grouting contractors do request these at the outset of a project, indicating that there is already an informal industry commitment to this type of approach.

Additional costs will, therefore, occur to the supervisory body through time spent drafting appropriate conditions. Such costs could be minimised by drafting some general guidelines in cooperation with producers and trade associations that would form the basis for the site specific conditions. Based on the conditions specified for use of chemical grouts in the Copenhagen Metro, the contractor would incur additional costs through the need to:

- survey the area to ensure that there are no water supply interests; and
- separate, collect, analyse and, where necessary, dispose of water and soil/rock coming into contact with the grout in a suitable manner.

The prevention of incidents such as that at Hallandsås will clearly have significant benefits. The SEK 26 million (£1.9 million, €3 million) paid out indicates this¹⁹.

The costs associated with specifying conditions will obviously vary depending on the size and complexity of the project, the amount of monitoring and sampling required, and the need for any changes from normal working practices (e.g. equipment used, hours of working, etc.). The range of activities involved makes it difficult to provide an estimate of likely costs. An upper estimate of the potential costs can be taken, however, from the present value (PV) costs of NOK 15.3 million (£1.2 million; €1.9 million) estimated by NSB as the costs of ensuring that drinking water was not affected by further grouting work (VISTA Utredning AS, 1998).

These costs, which are likely to be an over-estimate given the need for NSB to regain the confidence of local people and the importance of drinking water in the area (some of which supplies Oslo), are outweighed by the benefits from claims paid out (assuming

¹⁹ As noted above, this does not include an estimate of the environmental and ecological costs and, hence, is an underestimate of the true damages caused by the incident.

similar levels of benefits would accrue in Norway as in Sweden) and reduced pumping and treating costs and, hence, this option appears justified (within the constraints of the assumptions used).

Monitorability

Monitoring of the work is the key to ensuring that the risks are minimised. Providing that there is good communication between all parties involved, and that the individual responsibilities of these parties are clearly defined at the outset, monitoring should be limited to undertaking site visits and analyses of water, soil, etc. The level of sampling should depend upon the volumes of grout being used and, hence, would vary from site to site.

Good communication between the parties will also be important if the conditions are subject to change following any unexpected changes in geology, hydrogeology, hydrology, etc.

Suitability as an Environmental Agreement

Specified conditions of use are a very cost-effective method of reducing environmental risks. They provide coverage of the total sector since the conditions are applied at the use stage and acrylamide and NMA grouts could not be applied without such conditions being set. Industry would be required to work with the supervisory bodies to ensure transparency, which would require some extension of current approaches (e.g. further development of Method Statements and Environmental Impact Assessments).

Compliance with the EC Treaty would generally be attained, although there may be some impact on competition where large companies are able to provide more detailed information (based on previous work or a stronger relationship with suppliers) than smaller companies. This may encourage supervisory bodies to work with the larger companies at the expense of smaller firms. However as already noted, most chemical grouting work is carried out by specialist firms, all of whom will have the necessary expertise to advise supervisory bodies, regardless of their size.

Specified conditions of use are particularly suitable for environmental agreements since (compared with the list of factors identified by the European Environment Agency as to when environmental agreements are most suitable and when implementation is most effective (EEA, 1997)):

- companies party to the agreements would be a relatively small number of specialist grouting contractors, many of whom have been involved in the use of Method Statements and Environmental Impact Assessments;
- free-riding is not possible since the conditions will be set down at the point of use;

- the number of sources of pollution is limited (point sources), although the environmental problems which may occur if the agreements are not followed may be serious;
- third parties (i.e. the supervisory bodies) would be involved in the design and application of the agreements;
- the baseline will be prevention of environmental problems which can be assessed through monitoring as the work proceeds (and these will be clearly specified at the outset);
- the costs of complying with the agreement will be limited and would be similar for all grouting contractors (although costs will vary between projects); and
- supervisory bodies will have to set clear targets to be met/followed by grouting contractors.

5.4 Changes to the Material Safety Data Sheets and/or Labelling System

Effectiveness

There is a need for clearer labelling of grouts, in particular those which contain NMA as this is currently an area of confusion. It may be necessary, therefore, to require NMA to be consistently included within safety data sheets and/or on labels before specified conditions or certification measures could be introduced. Without this step, it may not be possible to ensure that the other risk reduction measures have captured all of the NMA grouts being used within the EU.

There are also potential problems with the lack of legislation which would allow the establishment of requirements for the classification and labelling of preparations which are dangerous to the environment. However, since both acrylamide and NMA grouts also pose risks to human health (and workers in particular) there is the potential for some improvement to the MSDS and/or labelling system.

Given that NMA makes up between 2% and 3% of a preparation and is found within the hardener component, it should be reported on safety data sheets²⁰. However, evidence from Norway regarding the Romeriksporten incident shows that this may not have been the case. It may be necessary, therefore, to enforce or modify the requirements as necessary. These modifications, however, are unlikely to reduce either the environmental or human health risks sufficiently unless this measure is used in combination with another. Hence, the potential for mis-application would remain.

²⁰ NMA is moderately toxic, although it is much less toxic than acrylamide. It does still show some evidence of being a carcinogen (NTP Chemical Repository (1991): *N-Methylolacrylamide*, article downloaded from http://ntp-db.niehs.nih.gov/NTP_Reports/NTP_Chem_H&S/NTP_Chem9/Radian924-42-5.txt).

Risks to worker health may be reduced if contractors are more aware of the substances that they are working with. The major concern in Norway, for example, was that the users of the grout did not know that they were using a product containing acrylamide. Had they known, they may have taken additional safety precautions which would have reduced the exposure of workers and potentially reduced the environmental effects as well.

Practicality

The method of producing safety data sheets is set out in various EC Directives (EC 67/548/EEC, EC 79/83 I/EEC and EC 88/379/EEC) and changes to these may require additional amendments to be made. Labelling of grouts containing acrylamide would be required under EC Directive 1999/43/EC²¹. Labelling of grouts containing NMA may be more problematic since this is not in Annex I of 67/58/EEC. However, since acrylamide is formed from NMA and, therefore, it is impossible to have a grout containing NMA which would not contain acrylamide, the potential exists for NMA grouts having to be labelled similarly to acrylamide grouts (providing the concentrations present exceed the trigger limits set under the relevant directives).

Economic Impact

As noted above, the economic impact would fall mainly on the regulators (both the EC to amend the relevant Directives and then on Member States in order to implement the new rules at the national level). The justification for such a move could be made based on the £1.9 million (€3 million) worth of claims made following the Hallandsås incident, where this is an underestimate of the 'true' benefits since it does not include a value for the environmental and ecological damages.

The costs of additional labelling are expected to be low given that Directive 99/43/EC has already been agreed and, thus, there is already a mechanism in place. In addition, MSDS received from some grout producers currently contain sufficient information to allow the inclusion (or otherwise) of NMA to be inferred. The main economic impact would, therefore, fall onto those companies whose MSDS are not currently as detailed.

The expense involved in introducing this measure would be the precursor to further economic impact as either the specified conditions or certification measure is introduced since this measure alone is unlikely to sufficiently reduce the risks.

Monitorability

Monitoring of labelling and/or safety data sheets should be relatively straightforward since all of the information is displayed on containers or is readily available from the manufacturers. However, this approach relies on the information given being correct. There may be an additional requirement that checks can be made on the components of

²¹ Directive 1999/43/EC amends Directive 76/769/EEC and relates to restrictions on the marketing and use of certain dangerous substances and preparations, Official Journal L166, 1 July 1999, pp 0087-0090.

a grout. This may be difficult if the composition is unknown or is unclear since any analyses that may be required may not focus on the correct chemicals.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of the Risks from Acrylamide and NMA Grouts

Although the Risk Assessment was unable to identify whether or not acrylamide and NMA grouts are currently being used in the EU, consultation has indicated that small levels of use may be occurring, with one potential site for this being the Metro Project in Copenhagen. It is believed that limited use is also likely to occur in other EU countries, but this has been unconfirmed. Two potential suppliers to the EU market have been identified, however, with one of these being a company located within the EU and another outside the EU (there may also be further suppliers but this has not been confirmed).

The draft environmental Risk Assessment (Environment Agency, 1999) concluded that there is a need for limiting the risks to aquatic organisms following the use of acrylamide and NMA grouts for construction; and that existing risk reduction measures should be taken into account. This conclusion was based on measurements taken following the incidents at Hallandsås, Sweden and Romeriksporten, Norway and, therefore, reflects the risks associated with mis-application of these grouts. There was insufficient data available for an assessment to be made of the grouts in 'normal' use, but consultation has indicated that it is possible to use these grouts without causing adverse impacts on the environment²². Indeed, the conclusion for use of acrylamide and NMA grouts in sewer repairs is that no further risk reduction measures are required at present.

The draft human health Risk Assessment (HSE, 1996 and 1999) also found that for large-scale uses, the risks to workers are unacceptable due to high exposure levels. Risks from small-scale uses, however, were estimated to be negligible and it was concluded that there is no need for further risk reduction measures for these applications (where these include specialist construction uses). The final human health risk assessment and associated risk reduction strategy are currently being completed.

6.2 Recommended Risk Reduction Measures

Given that limited use of these grouts may currently be taking place or may take place in the future, some form of risk reduction should be considered. Table 6.1 summarises the risk reduction measures according to their effectiveness, practicality, economic impact and monitorability as required by the *Technical Guidance Document on Development of Risk Reduction Strategies*. These are:

- marketing and use restrictions;
- a certification system (the success of which would depend upon industry's commitment to the system);
- specified conditions for use; and

²² Rhoca-Gil was used in Europe for 30 years and had been regularly used in Norway since 1981 (Aftenposten, 1997a and c).

Table 6.1: Comparison of the Risk Reduction Measures

Criterion	Marketing and Use Restrictions	Certification System	Conditions for Use	Changes to MSDS and/or Labelling
Effectiveness	Very effective in reducing risks from these substances but may give rise to other risks with the use of some substitutes	Dependent on industry's commitment and willingness to implement in strict terms	Very effective on environmental risks; limited effectiveness for risks to workers ¹	May be some reduction in environmental risks through increased awareness; may be some reduction in risks to workers; would need to be supplemented by another risk reduction measure
Practicality	Very practical for acrylamide grouts but more difficult for NMA grouts	May be some difficulties if chemistry of grouts is not transparent	Should be practical since conditions are applied to use of grouts rather than the grouts themselves (avoiding some of the labelling problems) providing the supervisory bodies are aware of risks and appropriate conditions for use	Need to distinguish between health and environment
Economic Impact	Direct costs may be high, although this will depend on the current market. Lower efficacy of substitutes may impact on the costs of specialist construction activities	May be significant for those wishing to continue use - may effectively act as a tax on acrylamide/NMA grouts ² . Some impact on the whole supply chain due to need to ensure that the grouts are chosen by those with sufficient knowledge and experience to make informed decisions as well as ensuring that the correct methods of application are followed	Some costs to regulators; possibly some impact on users if new equipment/working methods are required. Costs of monitoring and sampling, where required, may add additional impact for contractors	Impact mainly on producers and/or suppliers to ensure adequate information is provided to users
Monitorability	Straightforward for acrylamide grouts; more difficult for grouts containing NMA	More difficult to monitor and transparency of system would need to be ensured. Also required at two levels (users and suppliers)	Requires field visits and analyses to be taken, plus some reporting	Should be straightforward as information is given by manufacturers/suppliers; verification may be important

Notes: ¹ this is being considered separately in the human health risk assessment and risk reduction strategy

² This may have the advantage of encouraging research into more suitable alternatives

- changes to MSDS and labelling of grouts.

From the discussion provided in Section 5, it is possible to provide a subjective assessment of the relative effectiveness, practicality, economic impact and monitorability of the four potential risk reduction measures. Table 6.2 presents the results of this analysis using a qualitative scale running from large negative (---) through to large positive (+++).

Table 6.2: Qualitative Comparison of the Risk Reduction Measures				
Proposed Risk Reduction Measure	Effectiveness	Practicality	Economic Impact	Monitorability
Marketing and Use Restrictions	+++	+ to ++	---	+
Certification System	+ to ++	- to ++	--	- to +
Specified Conditions of Use	++ to +++	+++	--	++
Changes to MSDS and/or Labelling	0 to +	++	-	+++
Notes: +++ large positive; ++ moderate positive; + small positive; 0 neutral or no impact; - small negative; -- moderate negative; --- large negative				

Table 6.2 shows that marketing and use restrictions are considered the least preferred form of risk reduction. The unacceptable environmental risks identified to date from the use of acrylamide and NMA grouts have arisen as a result of their mis-application. Addressing the potential for such mis-use in the future should minimise any further potential risks, while at the same time not preventing these grouts from use in those applications (including the 1% of applications in specialised conditions) where efficacious substitutes do not exist. Furthermore, this ensures that there is no potential increase in human health risks associated with the adoption of the key alternatives.

Given the above conclusion, it is important that the other measures are combined in such a manner as to ensure that further mis-applications do not occur. In this regard, the first step recommended here is that the materials safety data sheets and labelling systems applied to these grouts are examined to ensure that those grouts containing NMA are readily identifiable. Furthermore, ‘use warnings’ should be incorporated in the labels to support either the adoption of a certification system or specified conditions of use.

Of these two options, the adoption of specified conditions for use is preferred to the adoption of a certification system²³. In particular, it is recommended that conditions are set which relate to:

²³ Specified conditions of use also fulfill more of the criteria identified by the European Commission (1996) and the European Environment Agency (EEA, 1997) for effective environmental agreements.

the types of applications in which their use is appropriate with regard to hydrology, rock, soil, temperature, etc. or associated with specific construction methods (e.g. NATM tunnels only);

details of the emergency actions which will be taken in the event of any difficulties arising with use of the grout (e.g. clean-up and disposal of contaminated soils, rocks and water); and

- collection and analysis of water and soil/rock that may come into contact with the grout during the grouting operation.

Such conditions may be best applied to all uses of these grouts, regardless of the scale. This avoids the problem of specifying a division between a small-scale and a large-scale use and also reflects that highly sensitive environmental areas may be affected even by small-scale uses. Supervisory bodies would be required to develop specified conditions of use in consultation with the contractors and these conditions would need to be agreed prior to any grouting taking place.

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ANNEX 1

LIST OF CONSULTEES

ANNEX 1: LIST OF COMPANIES CONTACTED

Overall response rate of 45%, ranging from 34% for trade associations and 46% for producers/suppliers of grouts to 100% for Government Departments.

Acrylamide Producers

Ciba Specialty Chemicals
Cytac Industries
SNF

Trade Associations

Acrylamide Monomer Producers Association (AMPA)
Association of Hungarian Consulting Engineers and Architects (AHCEA)
AI-Företagen
Associação Portuguesa de Projectistas E Consultores (APPC)
Asociación Española de Consultores en Ingeniería (ASINCE)
Asociación Española de los Tuneles (AETOS)
Association Belge des Techniques et l'Urbanisme Souterrain
Association Française des Travaux en Souterrain (AFTES)
Association of Consulting Engineers (ACE)
Association of Consulting Engineers in Ireland (ACEI)
Bund Deutscher Baumeister (BDB)
BK Swedish Rock Construction Committee
British Adhesives and Sealants Association (BASA)
British Association for Chemical Specialties (BACS)
British Chemical Distributors and Traders Association
British Tunnelling Society
Bundessektion Ingenieurkonsultenten (BS-Ing)
Chambre des Ingénieurs-Conseils de France (CICF)
Concrete Repair Association
Consiglio Nazionale Delle Ricerche - Societa Italiana Galleri
Danish International Consultants Organisation (DICO)
Danish Society for Tunnels and Underground Works (DTU)
European Federation of Foundation Contractors
European Federation of Piling Specialists
Fachverband Technische Büros Ingenieurbüros (FTBI)
Federation for the Repair and Protection of Structures
Federchimica
Foreningen Af Rådgivende Ingeniører (FRI)
Greek Tunnelling Society
Groupe Spécialisé pour les Travaux Souterrains (GTS)
Hellenic Association of Consulting Firms (HELLASCO)
Ingenieurverband Wasser- und Abfallwirtschaft e.v. (INGEWA)
International Federation of Consulting Engineers (FIDIC)
International Society for Trenchless Technology
International Tunnelling Association (ITA-AITES)

Annex 1: List of Consultees

Italian Association of Consulting Engineers (OICE)
Norsk Forening For Fjellsprengningsteknikk (NFF)
North American Grout Marketing Association (NAGMA)
Ordre des Architectes et des Ingénieurs-Conseils (OAI)
Organisatie van Nederlandse Raadgevende Ingenieursbureaus (ONRI)
Orde van Raadgevende Ingenieurs en engineeringbureaus - Ordre des Ingénieurs Conseils et des Bureaux d'Ingenierie (ORI)
P.A. Osterreichischer Betonverein
Rådgivende Ingeniørers Forening (RIF)
Sewer Renovation Federation
Stowarzyszenie Inżynierów Doradców I Rzeczoznawców (SIDIR)
Suunnittelu- ja Konsulttitoimistojen Liito (SKOL)
Sociedade Portuguesa de Geotechnia
Chambre Syndicale des Sociétés d'Etudes Techniques et d'Ingenierie (SYNTEC)
Asociación Española de Empresas Consultoras de Ingenieria Civil (TECNIBERIA)
Union Suisse des Ingénieurs-Conseils (USIC)
Verband Berantender Ingenieure (VBI)
Verband Unabhängig Beratender Ingenieurfirmen e.V. (VUBI)

Producers/Suppliers of Grouts

ABCR - Gelest (UK) Ltd
Alfa
Avanti International
Avonchem Limited
BIP Limited
Blagdon & Marlow Chemicals Ltd
British Traders & Suppliers Ltd
CarboTech
Chugai Boyeki (UK) Ltd
CMS Pozament
Cornelius Group Ltd
De Neef
Grace Construction Products
ITEC Consult
Lancaster Synthesis Limited
MBT International Underground Construction Group
Merck Limited
Mitsubishi (UK) Ltd
Mitsui and Co. UK Ltd
Phoenix Chemicals Limited
Quick-Mix
Transol Chemicals (UK) Ltd
Weber
Wex Chemicals
Whitchem Ltd
Willich Fosroc

Potential Users

AMEC
Dorsch Consult
Drainmasters
ECO Grouting
Geoconsult
Golder Associates
Keller Foundations
Soletanche-Bachy
Stent Foundations

Environmental Groups

Bellona (Norway)

Government Departments

Swedish National Chemicals Inspectorate
Swedish Ministry of Environment
Health and Safety Executive (HSE) UK
United States Environmental Protection Agency (US EPA)

