RISK ASSESSMENT OF CONCRETE FLUE LINERS

FINAL REPORT

Prepared by

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For

DEPARTMENT OF ENVIRONMENT TRANSPORT AND THE REGIONS

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Glossary

ADJ	Approved Document J
BS	British Standard
CEN TC	A Committee drafting European Standards
CO	Carbon Monoxide
DETR	Department of Environment Transport and Regions
DTI	Department of Trade and Industry
EN	European Standard
HAC	High Alumina Cement
HETAS	Heating Equipment Testing Approval Service Limited
HSE	Health & Safety Executive
KBA	Kiln Burnt Aggregate
LECA	Light Expanded Clay Aggregate
LYTAG	Light Expanded Concrete Aggregate (Brand Name)
NACS	National Association of Chimney Sweeps
NHBC Guarantee	National House Builders Confederation Guarantee
OPC	Ordinary Portland Cement
PrEN	Provisional European Standards
QA	Quality Assurance
SFA	Solid Fuel Association

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The authors are grateful to all members of the "CRE Expert Group", to industrial contacts and to colleagues at CRE Group Ltd.

EXECUTIVE SUMMARY

Introduction.

1. During 1998 questions were raised in the press regarding the safety of a brand of flue liner manufactured from concrete with a high sand content. There was concern expressed that this type of liner might be less robust than other types and that it could contribute to a higher risk of problems from combustion fumes entering buildings. This led Construction Minister Nick Raynsford to offer as part of his response to a Parliamentary Question that a risk assessment analysis would be conducted. As a result the DETR let a contract with CRE Group Ltd supported by a CRE Expert Group of subcontractors. This Group was to advise upon the number of flues that could create a hazard, or risk, to users, the nature and degree of this risk and the remedial action that should be taken to minimise both current and future risks.

Additional risks.

2. A risk assessor was employed to collate this information, and other background data, and determine the level of risk that could be associated with these liners. The conclusion was that there is an additional risk "associated" with 3000 of these chimneys (containing high sand content liners and installed over solid fuel stoves) which could result in up to one death per year. A higher number of people than this would be expected to suffer some symptoms of carbon monoxide poisoning. The figure must be taken cautiously because of the absence of any supporting evidence from the field; indeed some in the CRE Expert Group felt this projected additional rate could be overstated and in reality the number of associated deaths, and poisonings, could be significantly fewer. This compares with the average risk from any closed solid fuel stove of about one death per 30,000 appliances per year and in the case of gas, one death per million appliances per year. It should be noted that this risk is "associated with" not "caused by"; regular and effective sweeping and maintenance could minimise, and in theory eliminate, the actual hazard in a particular situation. This assessment of additional risk has been based on the interpretation of limited evidence and assumption and consequently the assessed risk may be too high or too low. In any case the extremes of extra risk are likely to be in the range of zero to one death per year.

3. The increased risk currently projected to be associated with these liners of high sand content derives from their performance during the simulated domestic trials, reinforced by their failure to complete the continuous firing test from a proposed European Standard, prEN1857 for category T600. It is known that chimneys in poor condition and/or having damaged liners are much more likely to be associated with deaths or injuries due to carbon monoxide poisoning. Thus 58% of carbon monoxide deaths arise where there are such problems, whereas the typical incidence of such defective chimneys in the total housing stock is believed to be nearer 5% to 10%, although this latter figure may rise in country districts.

4. A spread of liner conditions is expected in the field, thus occasional combustion of wood, in a stove used for essentially aesthetic or supplementary purposes is expected to give less liner damage than regular use with bituminous coal. It is difficult to predict performance with smokeless

fuel, although high efficiency appliances, with correspondingly lower flue gas temperatures, may be expected to lead to less initial damage. Any action plan derived from this data may need reflect this range of possible chimney status.

5. The CRE Expert Group is not in a position to comment upon the acceptability of this risk, but recommends further investigation to identify the current condition of a sample of these liners in the field.

Considerations.

6. Our reasons for these conclusions and recommendations in relation to these and other issues are as follows:

7. The principal hazard arising from defective chimneys is likely to be blockages leading to carbon monoxide poisoning and the installation likely to give the greatest risk is where a chimney serves a closed solid fuel stove. The reasons for this are that the flue gases from solid fuel stoves are frequently at a sufficiently high temperature to challenge flue linings mechanical strength and have a high content of carbon monoxide. Widespread investigations failed to find evidence of problems arising from these liners in the field, however most are less than ten years old.

8. At the beginning of this risk assessment, the possibility of undertaking a series of individual house inspections was considered for this type of high sand content liner. This was rejected by the DETR on practical grounds as the nature of any possible problems could not be defined and without this knowledge it was felt the actual investigation could have caused unnecessary concern. One of the original causes of the doubt surrounding these liners was their failure to pass a proposed European Standard for such products. This, of itself, does not necessarily condemn an existing product already in use.

9. Chimneys, in a similarly cracked state to that seen in the laboratory, are known to cause problems in the field. The cracks allow cold air to enter the flue, which weakens the draught and, over a solid fuel appliance, increases the rate of deposit of soot on the chimney walls. These increased soot deposits, if not removed by regular cleaning, offer a greater risk of spontaneously falling and blocking the outlet of the appliance. The appliance is then highly likely to spill carbon monoxide into the living area.

Number of deaths and near misses.

10. A survey was carried out of recent deaths and “near misses” arising from domestic solid fuel appliances and their causes. It should be noted that solid fuel now constitutes only a small percentage of the UK domestic energy supplies. Only 730,000 homes have a closed solid fuel appliance, although there is a modest market trend towards this number increasing. This means currently the vast majority of flue liners operate over gas appliances and/or open fires, both of which give low flue temperatures and do not subject the liner to arduous duty unless a chimney fire were to occur. Discussions with the manufacturer indicated that between 40,000 and 50,000 chimneys with high sand content liners are installed in the UK: about 3000 are thought to be fired with a solid fuel stove. These liners are thought to have a composition similar to those tested in this Programme, which were manufactured in 1996.

Competent persons.

11. In the absence of appropriate field data at this time, detailing the condition of high sand content liners, no definitive plan as to how to address this risk can be offered. It is however recommended that the DETR makes a general step to improve the level of knowledge and confirm the competence of chimney sweeps and solid fuel appliance installers. Many of these operatives are self-employed, were trained (if trained at all) many years ago and have little up to date information on current problems, and how to address them. Householders should be encouraged to only employ competent and registered operatives, and to survey their flues regularly. Sweeping a flue does not repair it, but a clean flue offers less resistance to the flow of flue gases and there is much less hazard of a soot fall; there is thus less likelihood of combustion gases spilling into the living space. A good sweep, ideally trained and registered, will be able to pass onto the householder a report as to the general condition of the chimney, and whether a full inspection and possible subsequent building work is recommended. It is recommended that a competent person should formally sign off all, both new and repaired, construction work on a chimney.

Composition of flue liners.

12. A further aspect to the contract was to recommend to the DETR a maximum sand content for concrete liners. During the investigation it has become clear from manufacturers and other experts that the performance of flue liners is too complex to be defined only by "Approved" materials of composition. Thus total composition, design and manufacturing technique are all very significant. Sand content is not a unique indicator of liner performance; this problem is exacerbated by the difficulty of defining such generic terms as sand, pumice etc.

Type Testing.

13. Thus the continued use of very broad generic terms such as "sand" or "pumice" within Building Regulations, although accepted as satisfactory in the past, may be no longer considered to provide appropriate protection to the householder. It is thus believed only third party Type Tests, which demonstrate fitness for purpose of the whole product, and subsequent third party supervision of production QA can ensure householder safety. It is recommended that the UK Building Regulations change over from flue liners being approved upon "materials of composition" to being approved upon demonstration of compliance with European Type Tests. Such Type Testing as a concept is well proven. This would entail modification to Approved Document J.

Other types of flue liners.

14. During the course of this risk assessment another type of concrete flue liner manufactured from Kin Burnt Aggregate and High Alumina Cement was also tested. These materials are listed as acceptable within the current Approved Document J. The performance of this concrete also gave cause for concern, although less so than with the high sand content concrete. The unexpectedly rapid deterioration of both products gives further weight to the recommendation that all liners should be Type Tested.

European Standards.

15. European Standards are currently being produced for a variety of chimney products. BS/EN1457 (1999) covers clay liners and prEN1857 concrete flue liners; these standards are wide ranging in their scope and include categories of flues suitable for most appliances for all fuels. These individual categories are then designated by a system of code letters that define the suitability of the chimney product for a range of environments. The most important of these being the maximum temperature of continuous operation, resistance to soot fires and class of permeability. Thus a flue liner designated T600, S, N1 would indicate a flue liner is suitable for continuous operation at 600C, that the liner is soot fire resistant and that it lies within the highest class of resistance to permeability. (Provisional European Standards, designated a prEN, are available from the British Standards Institute to interested parties.)

16. It is interesting to note that liners with a substantial sand content, (although by analysis with a somewhat higher cement content than those tested at CRE), have successfully completed long term cyclic trials, based upon a procedure devised for the Department of the Environment in 1987. In these tests a chimney containing liners with a high sand content were heated with an indirect gas flame (i.e. the flame was outside the chimney) producing flue gases up to 1000°C. It must be said that results of such tests are strongly dependant upon the precise details of the firing system, and a significant difference in the behaviour of liners when heated with gases of difference radiance has been noted previously. The test work does however provide support to the concept that a liner should be considered as a total product rather than purely from its materials of construction.

17. Whilst the CRE Expert Group strongly recommends the transition to type Tests, and specifically the use of prEN1857 (when adopted) and EN1457, some caution is suggested to ensure that details of these standards do entirely demonstrate "fitness for purpose" in a UK situation. UK liners may experience more severe duty than those on the Continent because the UK burns more bituminous coal and less wood, and our appliances are often physically smaller. It is recommended that a range of chimney products that have passed the new standards are assessed, on a one-off basis, through the same simulated domestic cycle used to test the liner of high sand content. This would be a simple test to validate the EN in a UK context. It is believed that these products will show no significant deterioration in this test. If any particular problems were to occur the reasons could be investigated and suggestions made for the Type Test to be extended and/or modified to detect these shortfalls in performance.

Test work carried out at CRE Group Ltd.

18. Three chimneys were constructed as part of this CRE Expert Programme, two (designated Chimney A & B) investigated the performance under a simulated domestic firing cycle, as might be used in a cottage without central heating. The third chimney (designated Chimney C) simulated a chimney fire. Chimney A (with a high sand content liner) was installed with thermal insulation, Chimney B with a liner made from High Alumina Cement and Kiln Burnt Aggregate, no thermal insulation was incorporated. Temperature data is available in the main text, including temperature when burning bituminous coal, wood and anthracite. Both peak and mean flue gas temperatures with bituminous coal were substantially higher than with anthracite or wood. The

condition of Chimney A was poor at the end of the test for about 1.4 metres above the flue entry pipe: the condition of the concrete used in Chimney B also gave considerable concern in this zone. The inside surface of the latter liner was particularly soft. Despite these defects, it must be reported that, neither Chimney A nor B leaked combustion gases into the laboratory and both chimneys provided sufficient draught for correct operation of the multifuel stoves. It is quite possible that the damage could have remained unnoticed or given a low-priority by the householder for some time. Chimney C gave information on the extremely rapid rise of temperature of the liner itself during a chimney fire, due to radiative heat transfer. It would appear that it is the rate of temperature rise of liners, as well as absolute temperature reached, that is important for their mechanical integrity.

19. After only 10 days firing the conclusion of the CRE Expert Group was that the high sand liner was in such a condition that extended laxity by the householder (for example infrequent professional sweeping, ineffective DIY sweeping, burning unseasoned wood, etc), combined with, say, a heavy rainstorm, could result in a blockage and a carbon monoxide incident. It was felt this risk could only increase with time. This view was strongly supported by the weakness of the liner; it could be crumbled in the hand, and the micro-cracking reported by a concrete laboratory. Whilst it is known that many liners in the field have deteriorated more quickly than originally anticipated, it is recommended that liners that show this behaviour after only 10 days should be carefully assessed, by means of field investigations. Fortunately the great majority of defective chimneys are identified by the householder, or sweep, before a serious incident occurs; for example the householder may smell fume, see smoke, notice staining, detect a deterioration in the heating performance of the appliance, or notice some other untoward occurrence. However, because it takes the householder a finite time to identify the problem, carbon monoxide poisoning from low concentrations of this gas may be relatively widespread. This ability of the majority of householders to eventually identify problems should in no way be considered to reduce the real risks that are, or will be, present if the condition of the liners in the field mirrors that in the laboratory. This analysis is based upon the premise that the liners tested were representative of those in production from the early 1990's to 1998.

Other problems.

20. This investigation has uncovered a range of problems associated with the construction of chimneys in the UK. It was the view of several senior figures in the domestic solid fuel industry that poor quality construction, or re-construction. of chimneys was a more immediate problem than possible short falls in materials of construction. As stated above, many operatives in the chimney industry have no formal training and no independent assessment of competence is carried out. The introduction of such schemes has been shown to be beneficial in general industry.

The role of competent persons.

21. The greater recognition and registration of “competent” persons, especially chimney sweeps, would be of assistance to householders. The organisation that operates such a register should also act as a clearing house to disseminate information to generally raise the level of knowledge within the chimney industry. There is currently no officially recognised register of

reported flue problems or a recognised advice centre for remedial actions. The National Association of Chimney Sweeps (NACS) is active in this area, and has a membership of about 250. This represents about 25% of professional sweeps, although it is known there are many more "part-time" operatives.

22. HETAS Ltd, which operates the approval scheme for the solid fuel industry, could take an increased role in this activity. It already works closely with NACS to approve sweeps. It is recommended that the DETR actively support and promote suitable industry initiatives.

Enhanced installation instructions.

23. The CRE Expert Group noted the sparse nature of some of the instructions supplied with some chimney products: if the European Standard Type Test Approval is to be successfully introduced more information should be provided, in particular which is suitable for use on site. Appliance manufacturers should include European Designation of the chimney type they require, and chimney manufacturers should include detailed instructions. Compliance with such instructions is recommended as a criterion of compliance within a revised Approved Document J.

INTRODUCTION

The remit.

1. This risk assessment study was offered as part of the response to a Parliamentary Question (see Appendix E) concerning the potential risk to health from certain designs of concrete flue liner produced and marketed in recent years. Contract Specification led to the definitions of the aims of the study to be:

- To establish how many dwellings already built or under construction have chimneys with potentially risk creating concrete components
- To establish the possible additional risk to householders
- To seek national expert technical opinion as to what if any of the possible problems are real
- To provide advice on possible remedial measures

2. Based upon the above aims and criteria, a set of detailed requirements were laid out by the DETR, these, and the results of this study are given within Paragraph 105.

3. Further to the above remit in view of the difficulties in obtaining meaningful data, the DETR agreed that the investigation should also contain firing tests to simulate heavy domestic usage. This would also determine what effect if any two different flue constructions (i.e. with and without thermal insulation) might have upon the operating temperature of liners. The original tender documentation was modified during contract negotiations to include the construction of three test chimneys, the production of related test coupons, sample analysis and then execution of a test programme.

Composition of the expert group.

4. To fulfil the remit, a CRE Expert Group was established by CRE Group Ltd. They have taken evidence from a wide range of sources across the building industry as well as carrying out test work at CRE Group Ltd headquarters near Cheltenham.

Membership included:

Crowther, Mark, CRE Group Ltd;
Dowsett, Brian, Zurich Insurance, Risk Control;
Trayhorn, Mark, Watson Wyatt, Risk Assessor;
Faucon,Philippe,CERIB.

Those individuals from companies with commercial interests in chimneys understood the importance of complete impartiality in their deliberations.

Background to European Chimney standards.

5. European Standards are currently being produced for a variety of chimney products. BS/EN1457 (1999) covers clay liners and prEN1857 concrete flue liners; these standards are wide ranging in their scope and include categories of flues suitable for most appliances for all fuels. These individual categories are then designated by a system of code letters that define the suitability of the chimney product for a range of applications. The most important of these are maximum temperature of continuous operation, resistance to soot fire

and class of permeability. Thus a flue liner designated T600, S, N1 would indicate a flue liner is suitable for continuous operation at 600^{o}C, that the liner is soot fire resistant and that it lies within the highest class of resistance to permeability. Additional information is indicated by W or D for Wet or Dry operation, a number which indicates corrosion resistance and a value for the thermal resistance Rx.

High sand content liners.

6. One of the reasons for the instigation of this risk assessment was that certain liner products, with a high sand content, had failed a test to prEN1857 for a temperature category T600 product and that it had become public knowledge. (Evaluation of a flue liner to pr EN1857 (Nov 1997) Clauses 8.1, 8.2 & 8.3 BSRIA No 14199/1. Further details of this test are given in Paragraph 25.2. This led to the suggestion that these could fail in service. An analysis of a liner similar to those in question is given in Paragraph 29 (liner xxx). It has not been established that failure of a test to prEN 1857 proves that the product creates a substantial risk to health or property. It is common for products from one generation to fail tests carried out to the next generation of standards. This is almost inevitable with improving standards. Such a failure does not necessarily condemn the original product, although it may and should initiate discussion. It is suggested that one of the important factors in such a discussion must be verifiable confirmation of sub-standard performance or other problems from the field.

Material definition.

7. For clarity it is appreciated that it would appear convenient to define quantitatively the sand content of "high sand content liners", but this is difficult due to the vagueness of the definition of sand, which is essentially only broken fragments of a range of materials. Throughout this report a high sand content liner refers to one with an overall analysis and production technique similar to that within Chimney A (Paragraph 16) and BSRIA report 14199/1 (Paragraph 29). It excludes other liners which may have a high sand content, but which due to the other constituents, design or manufacturing technique may perform in a different fashion.

The exclusion of chimney refurbishment techniques.

8. As required by the detailed requirements of the DETR, the CRE Expert Group has concentrated upon the risks posed by factory made concrete liners of a high sand content. No consideration has been given to chimney refurbishment techniques, some of which include spraying concrete on the inside of a defective flue or casting a new concrete liner in-situ.

BACKGROUND

9. Since 1963 Building Regulations have required new flues to be lined with a separate liner. The need for this arose from the shortcomings known to be associated with pargetting, that is rendering the inside of brick flues with mortar, which was the standard technique prior to that date. Between then and the mid 1980s these liners were principally made from fired clay, but it was known that satisfactory liners could be made from refractory concrete and a number of companies made a range of different products varying from concrete block prefabricated chimneys to thin wall sectional liners. Especially

during the 1980’s there was increasing experimentation with pozzolanic products and an increasing replacement of High Alumina Cement with Ordinary Portland Cement. Since 1990 the use of these concrete products has grown substantially. Traditionally this “refractory concrete” was generically defined as a concrete suitable for high temperature use. Constituents were however defined as High Alumina Cement, and crushed Kiln Burnt Aggregate, or crushed fire brick or other specially prepared aggregate. BS 6461 Part 1 (1984) specifically excludes the use of aggregate containing certain unstable crystalline silica or limestone. The use of Portland cement was discouraged except in combination with Pozzilanic materials. For use in chimney linings it was also presumed the material should encapsulate the performance of heat resistant concrete i.e. any concrete which will not disintegrate when exposed to constant or cyclical heating at any temperature below which a ceramic bond is formed. These definitions have usually been written in a fairly general fashion so as not to inhibit innovation, but in so doing it has always been known they can encompass materials or blends which in a particular configuration or situation are not necessarily fit for purpose. For example variation of the water to cement ratio will very significantly effect the final properties of any component.

10. The CRE Expert Group made considerable efforts to obtain quantitative data on the performance of these concrete liners, on a type by type basis, These included discussions with the manufacturers themselves, district surveyors, insurance companies, chimney sweeps and builders. None of these could provide meaningful quantitative data on long term liner performance except in a very general fashion. Laid out below are three principal reasons for this:-

10.1 The quality of installation is commonly poor, with liners being cut, installed upside down, offsets made up with mortar, and other malpractice’s being followed upon site. Some sources suggest that the majority of new installations are faulty to some degree. This makes the correct identification of the root cause of any increased risks that may arise very difficult, and obscures any quality problems. This is particularly so in a post construction dispute.

10.2 Solid fuel, which is the only fuel likely to challenge liners to their design limits, now contributes only a very small percentage of total UK household energy supplies. Only 730,000 homes, out a total of over 20m, have a closed solid fuel stove. This means that the vast majority of flue liners operate over gas appliances and/or open fires both of which have low flue temperatures and do not subject the liner to arduous duty. Thus the absolute number of liners, over solid fuel appliances, that may give problems is small, and problems may tend to go unnoticed. A CORGI operative is only required to carry out a flue clearance test, not a full smoke test, when fitting a gas appliance. Many defective flues therefore may go unreported.

10.3 There is very little feed back mechanism for the manufacturers to learn of shortcomings, if any, of their own products as it is very difficult, often impossible, to identify the brand installed within any particular chimney, and thus there would appear to be no easy route of complaint.

11. Because of the sparsity of the data, the concept adopted by the CRE Expert Group to establish the performance of high sand content liners was as follows:-

11.1 Identify the causes of the recent deaths and near misses reported to the Solid Fuel Association and investigate whether a pattern existed. This should show whether certain types of lined chimneys, either generally or of a specific type, were more or less likely to be associated with incidents.

11.2 Identify what percentage of lined flues currently may be defective.

11.3 Initiate testwork at CRE to investigate the performance of concrete flue liners currently on the market or that have been sold in the recent past.

11.4 Carry out a risk assessment based upon the above data.

EXPERIMENTAL PROGRAMME

12. A paper based assessment considered the flue gas temperatures and risk of poisoning from flue gas from a wide range of appliances. The CRE Expert Group rapidly concurred with the widely held view, that if an increased risk were to occur with certain liners, it would be primarily associated with the use of solid fuel closed stoves beneath these chimneys.

13. Two separate experimental Programmes were carried out:-

A simulation of a "Heavy duty domestic firing cycle".

13.1 Two chimneys were constructed, labelled A and B, the former (A) contained a number of liners made with a high sand content and the latter (B) contained liners of a more conventional composition made from high alumina cement and kiln burnt aggregate. Simultaneously the effect on liner wall temperature of operating with and without insulating backfill was investigated. The test program was limited by the liners of high sand content being in very short supply. It is felt appropriate to stress that chimneys A and B were not directly conceived as "test" and "control"; but to investigate a range of parameters to provide guidance as to the best method of determining the fitness for purpose of chimney liners. The detailed objectives were to:-

- To determine the performance of the material of construction of two flues, in particular evidence of macro- or micro-cracking of the concrete, loss of strength, increased porosity etc.
- To determine the maximum temperatures experienced by the liners within insulated and un-insulated chimneys. Temperatures at the mid point of the joints (i.e. midway between the inside and outside face of the liner) and upon the outer face of the liner were measured.
- To determine the effect of fuel (wood, bituminous coal and anthracite) upon liner temperatures, whilst under "normal" and "typical misuse" conditions. Rate of temperature rise was of particular interest.
- To compare the liner temperatures reached with those experienced during gas fired testwork carried out at CRE and by BSRIA.
- The peak and time averaged temperatures that occur within the flue of typical small multi-fuel stoves, whilst under "normal" and "typical misuse" conditions.

- To investigate the behaviour of a range of concretes of different composition Test coupons were hung in the high temperature zone near the base of the flues.

Two complete chimneys (A and B) were built within the laboratory and fired for 10 days, according to a “heavy-duty domestic firing cycle” i.e. under normal and typical mis-use conditions. The liners of high sand content carried the same product identifier (xxx) as those used by BSRIA under contract 14199/1(Paragraph 29). The chimneys were fired with small multifuel stoves and the operating regime was as might be used in a small house without central heating. Whilst uncommon in towns, significant numbers of properties with such a heating arrangement remain in rural districts. Full details of the experimental programme are given in Appendix B.

A simulation of a chimney fire.

13.2 To investigate the temperatures reached during soot fires, and rate of rise of liner temperature, a further chimney (C) was constructed. This was a vertical assembly of flue liners supported by a steel joist.

14. During the construction of Chimney C, the outer blockwork was omitted in order to view the liners during the fire. This chimney would give information on the maximum temperatures reached during chimney fires, and the rate of temperature increase. During design of the Programme it was thought (with hindsight incorrectly) that there would be a simple relationship between maximum temperature reached by the liner wall and its physical condition after the test.

15. Full details of all tests are given in Appendix B. Chimneys A and B are shown schematically on page 13. The main purpose as to why Chimney A was insulated and Chimney B not insulated was to investigate the effect of this upon absolute liner temperature and temperature gradient. Thus the liner within Chimney B (no insulation) was expected to suffer an increased thermal gradient and thus thermal strain across the liner; but operate at a much reduced average liner temperature. Chimney specification was as follows :-

15.1 Chimney A - A flue of internal diameter 225mm, the lowest 2.2m of which was assembled from 9 liners from a single source manufactured with a high sand content. This was regarded as the most important section of the flue as temperatures are at their highest. This was the maximum number of these liners that could be obtained. Above this point the flues were continued with a mixture of High Alumina Cement (HAC)/Pumice and Ordinary Portland Cement (OPC)/Pumice liners. These liners were contained within a concrete block chimney 600mm outside dimension, the gap between liner and block work was filled with Light Expanded Clay Aggregate (LECA). This was then fired with a multifuel stove. The recommended size of flue for such a stove is 175 mm ID. Samples of liners for testing with a high sand content were only available with an ID of 225 mm hence the use of this size. This is also the diameter of the overwhelming majority of linings installed in the field as it gives the householder the option of either an open fire or a closed stove.

15.2 Chimney B - A flue 185mm square was assembled from High Alumina Cement (HAC)/Kiln Burnt Aggregate (KBA). The liners were contained within a concrete block chimney 450mm outside dimension, the small gap (up to 5mm) between the liner and blockwork was left empty. The liner had a slightly reduced wall thickness (between 24 and 28mm) compared to usual production of this type of liner, (25 to 30mm). This was fired with a multifuel stove. As discussed in paragraph 15.1, the recommended internal diameter for this application is 175 mm. As an uninsulated flue of conventional construction was required, a 185 mm square liner was chosen.

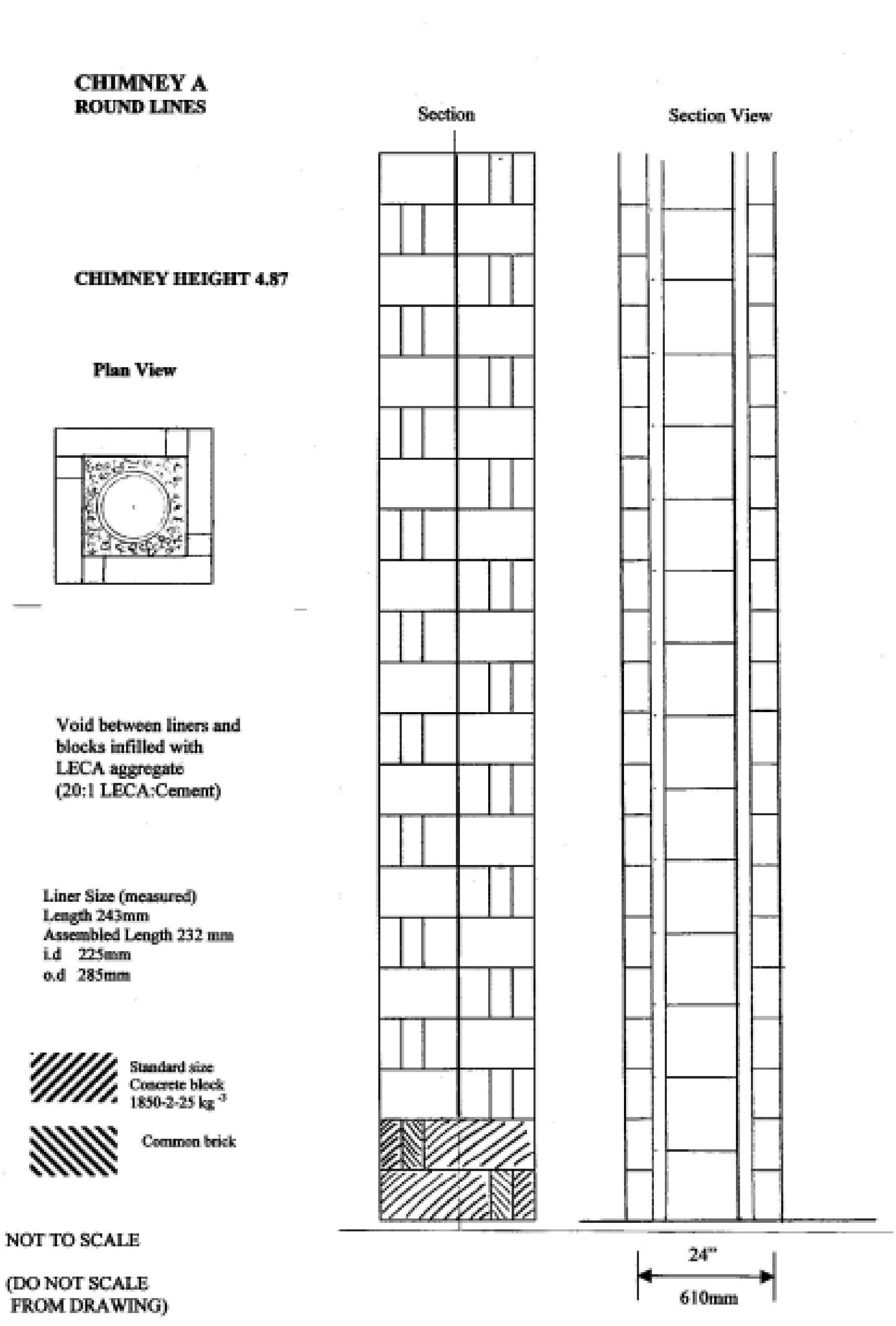
15.3 Two different chimney constructions were chosen because the temperature profiles of liners with and without insulation were required. Building a "free standing" flue within a larger chimney was clearly unacceptable and would correctly be seen as bad practice. At the outset of the Programme it was not known what the final condition of the high sand liner would be, neither was it known which fuel (bituminous coal, wood or anthracite) would give the highest flue or liner temperatures.

15.4 Chimney C - This was constructed of two sections, the top (approx. 1.4m) of concrete liners manufactured from HAC/Pumice and the lower (approx. 1.2m) made from Ordinary Portland Cement (OPC)/Pumice. This chimney was constructed to simulate a chimney fire. It was not subjected to a Domestic firing cycle.

16. The analyses of the concrete material of the flue liners under test were:-

	Chimney A* XXX Liner No1to 9	Chimney A OPC Round Liner No10 to 14	Chimney A HAC Round Liner No15 to 20	Chimney B
	% Volume	% Volume	% Volume	% Volume
Sand	21.8			
Paste	24.7	31.7	34.8	26
Pumice		54.5	58.7	
Lytag/Ash	30.1			73
Ironstone				
Void	23.4	13.8	6.5	1

* This product bore the same identifier as used for Chimney A of the CRE tests, and has been confirmed as the date of construction of the liner (29/4/96). This apparent change in composition is at variance with the advice given by the manufacturer. It should also be noted that these analyses have wide error bands of +/- 3 percentage points (minimum). Liners are numbered up from the base.


CHIMNEY A
ROUND LINES
CHIMNEY HEIGHT 4.87
Plan View
Void between liners and
blocks infilled with
LECA aggregate
(20:1 LECA:Cement)
Liner Size (measured)
Length 243mm
Assembled Length 232 mm
i.d 225mm
o.d 285mm
Standard size
Concrete block
1850-2-25 kg -3
Common brick
NOT TO SCALE
(DO NOT SCALE
FROM DRAWING)
Section
Section View
24"
610mm

CHIMNEY B
FLUE

CHIMNEY HEIGHT 4.87m

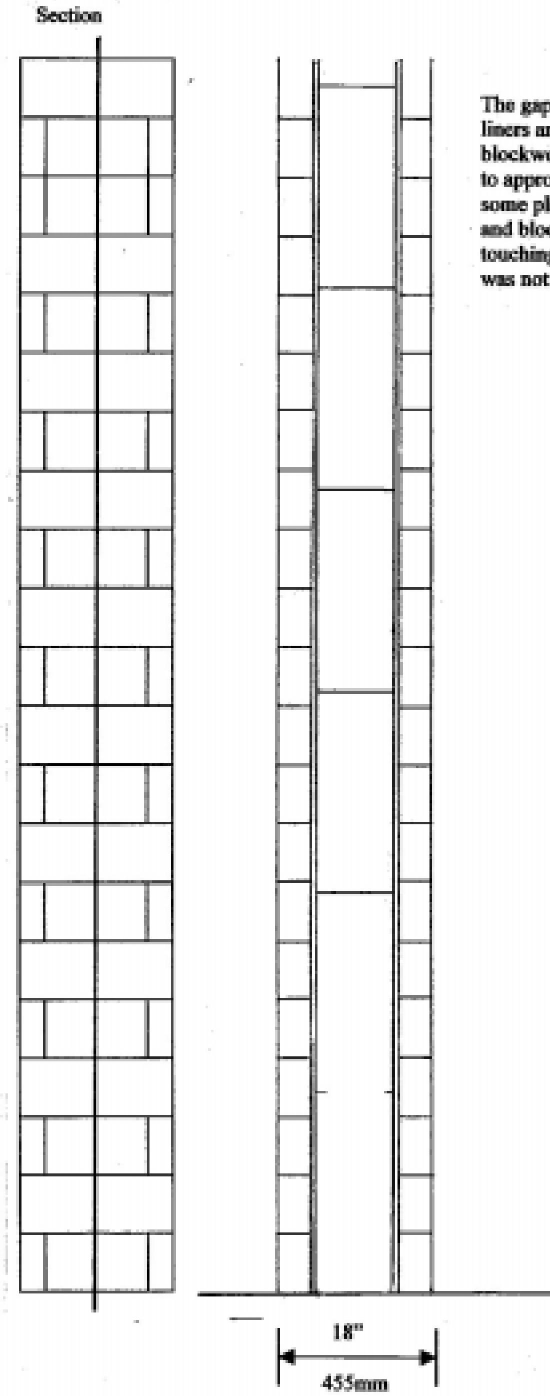
Liner Size (measured)

Length 620mm

Assembled Length 610 mm

Outside 230mm x 230mm

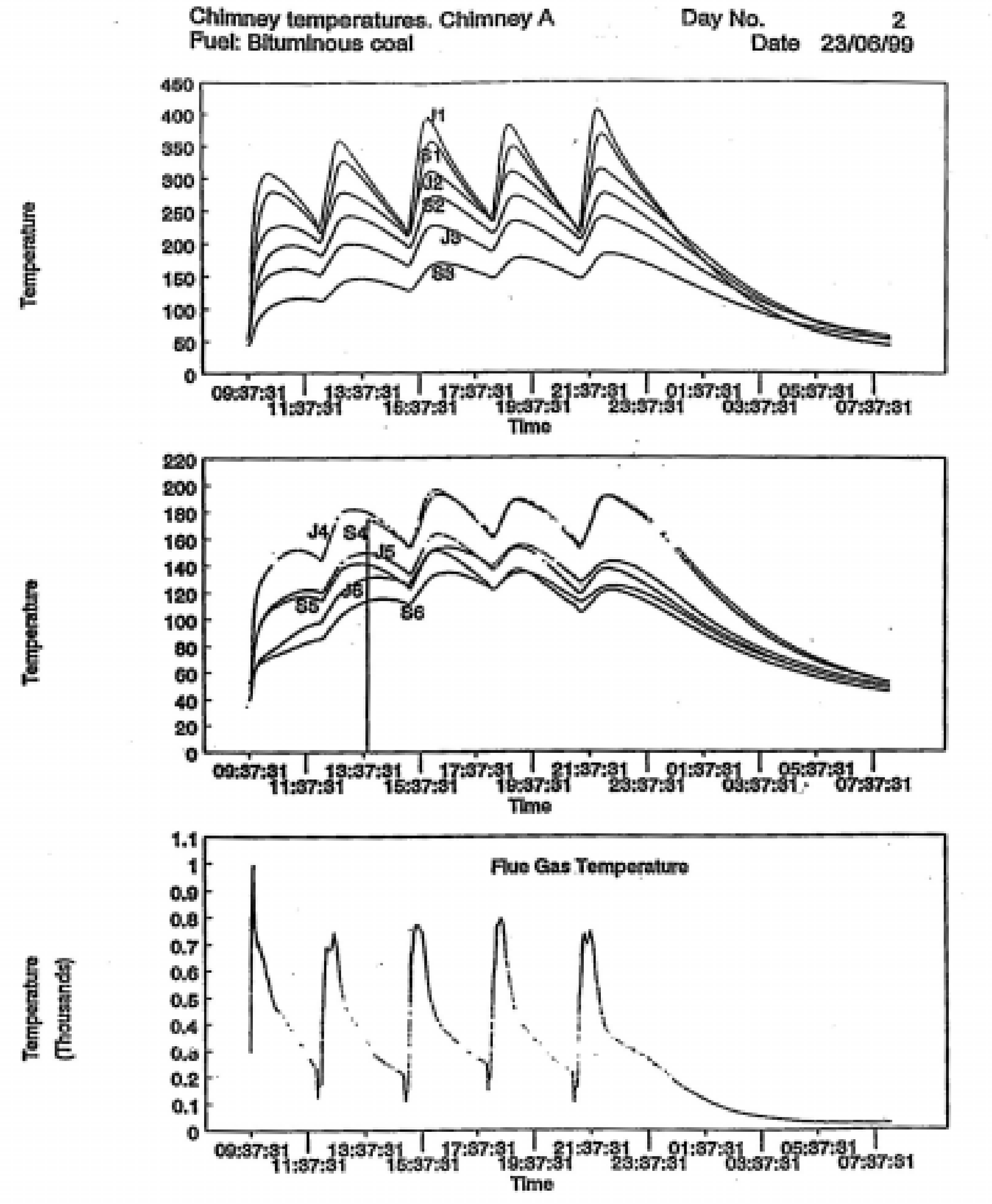
Inside 183mm x 183mm



The gap between the liners and the blockwork varied up to approx 5 mm. In some places the liner and block were touching. The gap was not infilled.

NOT TO SCALE

(DO NOT SCALE FROM DRAWING)



LINER AND FLUE GAS TEMPERATURES

17. **Summary of results from the "heavy duty domestic firing cycle".**

Both chimneys A and B provided sufficient draught to permit correct operation of the appliances and neither leaked combustion gases into the laboratory, even during the "ignition" and "going out" phases. The programme concentrated upon high fire operation when damage to the liner was thought most likely; due to budgetary restrictions no specific extended low fire tests could be carried out. One day of typical mis-use was included; this entailed operation with the ash pan door cover removed until the flue pipe could just be seen to glow dull red; this could easily reflect operation by a householder on an exceptionally cold and windy night. Chimney A showed significant external cracking; Chimney B showed hairline cracks only. At the end of the testwork both chimneys emitted smoke during a smoke test and upon dismantling the liners of both chimneys were found to be severely damaged for a distance of 1.2 to 1.4 m above the appliance flue pipe entry point. Both would have required substantial repair to be regarded as fit for purpose. Above 2m neither flue showed substantive damage. Cold static pressurisation tests after the thermal tests showed a leak rate for Chimney A of 8.0 $l/s/m^2$ and for Chimney B of 2.5$l/s/m^2$ both correct to 20Pa. The pre-test values were 1.07 $l/s/m^2$ and 0.12 $l/s/m^2$ respectively. Sweeping these straight flues from the top with a fibre brush did not dislodge any liner material. Such an absence of displaced liner material is to be expected after only 10 days of firing. As will be discussed later, routine sweeping of chimneys keeps them clean of soot deposits (thus reducing the risk of spontaneous falls) and such sweeping will reveal the substantial degradation that may occur from a sub-standard liner

18. Calculated air ingress values whilst under fire (during operation in closed stove mode) gave rates of 1.2 $l/s/m^2$ and 0.6 $l/s/m^2$ for Chimneys A and B respectively. No direct quantitative correlation between cold static and operational hot rates is expected, but it is interesting that the ratios are not that dissimilar i.e. when under fire Chimney A leaked twice the volume of Chimney B, increasing to a factor of threefold when cold. Reasonable parallels may thus be drawn between leakage rates under fire and when measured under static cold conditions. The principal problem arising during normal operation of a chimney is usually air leaking into the chimney (air in-leakage); this will be discussed in greater detail later. The rate of in-leakage a chimney is likely to experience is usually determined by measuring it's outward leak when pressurised. These rates (i.e. inward or outward) are expected to be similar at the same absolute differential pressure.

Maximum liner mid-wall temperatures.

19. A typical graph of temperature (Flue gas, mid-wall and outer liner wall) against time for Chimney A (Day 2) is given on Page 14. Thermocouples labelled "J" were mounted mid-way across the thickness of the liner wall, within a joint. Thermocouples labelled "S" were mounted on the outside face of the liner at an adjacent point. Hence thermocouples "J" would be expected to show a higher temperature than the corresponding "S". The five refuels are clearly visible. The cyclic traces are very typical of those from solid fuel appliances. For chimney A the following maximum mid-wall temperatures were recorded:-

Bituminous coal (Av. standard conditions)	400°C
Bituminous coal (Misuse)	520°C
Wood	280°C
Anthracite	260°C
Natural gas (1050°C)	530°C

For chimney B the following maximum mid-wall temperatures were recorded:-

Bituminous coal (Av. standard conditions)	280°C
Bituminous coal (Misuse)	390°C
Wood	230°C
Anthracite	200°C
Natural gas (1050°C)	420°C

Mid liner wall temperatures were thus significantly less, down between 150°C and 50°C, for Chimney B compared with Chimney A, as might be expected due to the absence of insulation. The maximum liner temperatures produced were slightly lower for anthracite than for wood, by typically 20-30°C, and in turn the values for wood were substantially less than those for bituminous coal, by typically 120°C in the case of Chimney A.

Consideration of these temperatures (and more detail provided within Appendix B) indicates that the surroundings of a liner are important to its operating temperature; as are the emmisivity and mass flow rate of the hot flue gas. This will be further discussed with reference to the BSRIA results (Paragraph 27). A fuel which produces a long flame of high radiance (for example bituminous coal) will produce higher flue wall temperatures, and greater thermal stress than for example a smokeless fuel such as anthracite. This would indicate that the greatest risk of flue failure occurs with bituminous coal.

Time averaged appliance flue gas temperatures were :-

Bituminous coal	450°C (even under mis-use)
Anthracite	400°C
Wood	280°C

20. The following table summarises the liners used to construct Chimney A and describes the final condition of the liners: - Note each liner is 250mm high.

Chimney A – Flue contained by LECA backfill inside 600mm blockwork stack							
Round							
No from top	No from btm	Height mm	Material	Comments	Ring	Inside	
1	20	4860	HAC/Pum	**No cracks**	Sharp	Soot	
2	19	4617	HAC/Pum	**No cracks**	Sharp	Soot	
3	18	4374	HAC/Pum	**No cracks**	Sharp	Soot	
4	17	4131	HAC/Pum	**No cracks**	Sharp	Soot	
5	16	3888	HAC/Pum	**No cracks**	Sharp	Soot	T/CNo6
6	15	3645	HAC/Pum	**No cracks**	Sharp	Soot	
7	14	3402	OPC/Pum	**No cracks**	Sharp	Soot	
8	13	3159	OPC/Pum	**No cracks**	Sharp	Soot	T/CNo5
9	12	2916	OPC/Pum	**No cracks**	Sharp	Soot	
10	11	2673	OPC/Pum	**No cracks**	Sharp	Soot	
11	10	2430	OPC/Pum	**No cracks**	Sharp	Soot	T/CNo4
12	9	2187	OPC/s/PF Ag	**No cracks**	Sharp	Soot	
13	8	1944	OPC/s/PF Ag	**No cracks**	Duller	Soot	
14	7	1701	OPC/s/PF Ag	**No cracks**	Duller	Soot	T/CNo3
15	6	1458	OPC/s/PF Ag	**Large tooth missing**		Half Soot	
16	5	1215	OPC/s/PF Ag	**Fine vert cracks**		Clean	
✶17	4	972	OPC/s/PF Ag	**Loss of integrity**		Clean	T/CNo2
✶18	3	729	OPC/s/PF Ag	**Loss of integrity**		Clean	
✶✶19	2	486	OPC/s/PF Ag	**Loss of integrity**		Clean	
✶✶✶20	1	243	OPC/s/PF Ag	**Severe cracks**		Clean	T/CNo1
HAC/Pum = High Alumina Cement & Pumice							
OPC/Pum = Ordinary Portland Cement & Pumice							
OPC/s/PFAg = OPC/Sand/Fly Ash Aggregate i.e. a high sand content liner							
✶Part of liners 17 &18 could not be separated and were severely broken							
✶✶Liner 19 had cracked into 6 large pieces							
✶✶✶Liner 20 was heavily cracked in several directions & very weak							
T/C	Indicates Thermocouple at top of liner						
Ring	Indicates the sound made by the liner when struck						

Air leakage rates are reported in Appendix B.

The following table summarises the liners used to construct Chimney B and describes the final condition of the liners:- Note the use of fewer liners as each is 600mm high.

Chimney B – Flue contained inside 450mm stack- no backfill							
Square							
No from top	No from btm	Height mm	Material	Comments	Ring	Inside	
1	8	4880	HAC/KBA	**No cracks**	Sharp	Soot	
2	7	4270	HAC/KBA	**No cracks**	Sharp	Soot	
3	6	3660	HAC/KBA	**No cracks**	Sharp	Soot	T/CNo6
4	5	3050	HAC/KBA	**No cracks**	Sharp	Soot	T/CNo5
5	4	2440	HAC/KBA	**No cracks**	Sharp	Soot	T/CNo4
6	3	1830	HAC/KBA	**No cracks**	Sharp	Soot in corners	T/CNo3
✶7	2	1220	HAC/KBA	**Cracks**	Dull	Clean	T/CNo2
✶✶8	1	610	HAC/KBA	**Loss of integrity**	Dull	Clean	T/CNo1
HAC/KBA = High Alumina Cement & Kiln Burnt Aggregate (also known as Lytag)							
✶**Liner 7 had a horizontal crack causing loss of two large sections & a vertical corner crack**							
✶✶**Liner 8 had cracked horizontally & vertically at a corner**							

Air leakage rates are reported in Appendix B.

21. The conclusion that can be drawn from the CRE tests is that the concrete near the base of both flues showed very significant deterioration and neither chimney A nor B finished the simulated firing conditions in a satisfactory physical condition. The air in-leakage measured whilst hot would lead to reduced draught, increased deposits, and an enhanced risk, especially during unusual wind conditions, of flue gas entering the living space.

Performance of HAC/Kiln Burnt Aggregate liner.

22. Although not the subject of this enquiry, it is clear that the microscopic damage to the lowest section of the HAC/Kiln burnt aggregate liner used within Chimney B was also substantial. Micro-cracking of the aggregate paste bond as well as micro cracks of the aggregate itself near the inner surface of the flue was reported. Such behaviour was not expected as HAC/Kiln Burnt Aggregate liners are permitted within the existing Approved Document J; no reports of problems with this material are known from the field.

The simulated chimney fire.

23. The following table summarises the liners used to construct Chimney C and describes the final condition of the liners:

Chimney C Flue built in open air. Central section wrapped with insulating blanket					
Round					
No from top	No from btm	Height mm	Material	Comments	Inside
1	11	2673	HAC/Pum	**Closed but signif.**	Soot
2	10	2430	HAC/Pum	**Closed but signif.**	Soot
3	9	2187	HAC/Pum	**No cracks**	Soot
4	8	1944	HAC/Pum	**2 substantial cracks**	Soot
5	7	1701	HAC/Pum	**2 substantial cracks**	Soot
6	6	1458	OPC/Pum	**No cracks**	Soot
7	5	1215	OPC/Pum	**No cracks**	Soot
8	4	972	OPC/Pum	**No cracks**	Soot
9	3	729	OPC/Pum	**No cracks**	Soot
10	2	486	OPC/Pum	**Vertical cracks**	Soot
11	1	243	OPC/Pum	**Loss of integrity**	Soot
HAC/Pum = High Alumina Cement & Pumice					
OPC/Pum = Ordinary Portland Cement & Pumice					
Liner numbers refer to numbering from top down					
Liners 1 & 2 were traversed by a "closed" but significant long vertical crack					
Liners 4 & 5 were traversed by 2 very substantial vertical cracks(1mm wide)					
Liner 5 had a substantial section missing (150mmX50mm, attached to No 6)					
Liner 11 was broken by three vertical cracks & loss of a large section (125mmX180mm)					

The simulated fire within Chimney C ignited well, and gave a similar outward appearance as a conventional chimney fire. During the simulation of the chimney fire significant cracks, approximately 1mm wide, opened on the external surface of the liners shortly after ignition. These closed as the temperature gradient across the liner decreased. These cracks however must have structurally weakened the liner at this point. Both the High Alumina Cement (HAC)/Pumice and Ordinary Portland Cement (OPC)/Pumice were affected. The rate of temperature rise of the mid point of the concrete liner was approximately 100°C per minute, this is over 10 times faster than seen during any other tests. This is an extremely arduous duty for any product and is a clear reason why repeated chimney fires are known to produce liner failure. Both the OPC and HAC/Pumice products suffered cracking during a simulated chimney fire. It may be noted that the maximum flue gas temperature recorded was 920°C, and the maximum wall temperature 350°C; this is not in itself considered a particularly high wall temperature. The latter is significantly less than those experienced during the misuse test with bituminous coal or during the test firing with natural gas at 1050°C. It should be noted that this 920°C is less than (but not very much less than) the 1100°C or 1000°C test temperatures required by the existing ADJ and the new EN respectively, but great caution is urged when attempting to define flue gas temperatures for test purposes.. As discussed previously the temperature experienced by a liner is a strong function of flue gas volume, emissivity, and temperature; the latter alone is insufficient. It is all these factors that will affect both the rate of temperature rise of the liner, the temperature gradient across the thickness of the liner, and the absolute temperatures reached; it is then these two latter factors combined with the design and material of construction of the liner that defines the liner's propensity to crack.. The information is thus not available to state whether the "correct" flue gas test temperature is 1000°C or 1100°C.

BSRIA TEST REPORTS

24. The CRE Expert Group was supplied with reports of work carried out by The Building Services Research and Information Association (BSRIA) on four products. These reports were provided by the commissioning clients of the work, and three of the reports describe tests to European Standards.

Performance of clay liner.

24.1 A 185mm ID circular clay liner constructed in accordance with BS1181 was tested with the intention to classify this product to prEN1457 class T600, S and N1. The first value (T600) indicates the liner should be suitable for appliances with a mean flue gas temperature of 600°C, the second value (S) means it should resist a soot fire and the third value (N1) is an indication that the highest category of air-tightness is required (<2.0l/m2/s at 40 Pa). Testing of the requisite assembly was discontinued after a large crack penetrated through the liner wall at a flue gas temperature of 550°C. (Evaluation of clay flue liners to prEN1457 (June 1998) Clauses 7.1,7.4,7.5,9.1, and 16.8 only BSRIA No 14566/2, February 1998).

Performance of high sand content concrete liner.

24.2 A 225mm round concrete liner with a high sand content of analysis shown below (xxx) was tested to prEN1857 November 1997. The liner was tested to T600, S and N1 or N2. After ten minutes at 700°C the test was abandoned due to three cracks opening up in the product to about 2mm. (Evaluation of a flue liner to prEn1857 (November 1997) Clauses 8.1, 8.2 & 8.3 BSRIA No. 14199/1, August 1998)

Performance of a typical concrete flue liner.

24.3 A 200mm square concrete liner of analysis shown below (BSRIA 14566/1, January 1999) was tested against the classification prEN1857 T600, S, N1. The first value indicates the liner should be suitable for appliances with a mean flue gas temperature of 600°C, the second value means it should resist a soot fire and the third value is an indication that the highest degree of air-tightness is required (<2.0l/m^2/s at 40 Pa). An analysis of the concrete is contained within paragraph 29. The liner did not achieve the desired N1 category having a leakage rate of (after testwork) equivalent to 3.4 l/m^2/s at 40 Pa (Evaluation of a flue liner to prEN1857 (Nov 1997) Clauses 7.1, 7.2, 8.1 and 8.3 only BSRIA No. 14566/1, January 1999).

Extended firing of a high sand content liner.

25. The fourth report concerned an extended firing trial. (Reference Thermal testing of a masonry and concrete flue assembly BSRIA No 14813/1 and 2, May 1999) A concrete liner 225mm ID circular of analysis given in paragraph 29 (i.e. of substantial sand content) was built into a chimney of external dimension 552 x 664mm and subjected to 12 thermal cycles, some using flue gas (from an external natural gas burner) up to 1000°C. The liner performed well with no sign of cracking or deterioration. At the end of the test the cold static leakage rate was 1.08 l/s/m^2 at 40 Pa. The Manufacturer states the

composition of the liner as typical of that produced over previous years. This test was based upon the procedure used by BSRIA when carrying out testwork for the Department of the Environment in 1987. With a nominal flue gas input temperature of 1000°C average highest midwall temperatures were 459°C, with a highest external liner surface temperature of 309°C.(Average of test cycle No3 and No4) The test periods were 30minutes, (Report on the testing of masonry chimneys April 1987; Contract 7562). These temperatures are less than those measured within the test work carried out upon Chimney A.. For comparison during the latter, under mis-use conditions (but at flue gas temperatures of only 925°C) the highest midwall temperature was 520°C, and highest external liner surface temperature 450°C. Under more typical conditions midwall temperatures were 400°C and external liner surface temperatures were 300°C to 340°C. The CRE testwork generally maintained higher temperatures for several hours. Flue gas temperatures and energy input rates to Chimney A (and B) were generally lower (10 to 20kW) than to the gas fired chimney at BSRIA (58kW).

Indirect vs. direct firing of liners.

26. In the original Dept. of Environment contract (April 1987) a clay lined brick chimney was fired both directly and indirectly with an oil burner. The indirect firing was carried out by mounting the burner outside the chimney and ducting the flue gases to the chimney, during direct firing the burner was placed within the chimney. Oil was chosen to be more representative of solid fuel combustion than would a gas burner with its lower radiant energy component. When direct fired a liner cracked even at a heat input of 20kW, and the surface temperatures reached at 30kW were only slightly less than those reached with 50kW (930°C) of indirect firing. 30kW(direct) shattered liner number 2. Such differences (together with the data within paragraph 25) suggest that (for similar flue gas temperatures) external firing with natural gas is likely to give less damage than firing with a multifuel stove, especially when the latter is burning a “long flame” bituminous coal. Quantifying these complex effects would require a further extensive research programme.

27. It must be accepted that there is a significant difference between the performance of the high sand liners fired within Chimney A, and those reported when fired at BSRIA (May 1999). It is not possible to explain whether this is due to the test method (ie externally fired natural gas vs the highly radiant flame from bituminous coal) or a difference in the properties of the flue liners tested, or a combination of the two factors.

28. A certificate has been issued for compliance with prEN1857 for a concrete flue liner (BSRIA Certificate No. 14523/3, November 1998). It should be noted that this product contains no added ‘sand’ and hence is of an entirely different composition to that discussed elsewhere in this report.

29. Analysis of products used in tests at BSRIA:-

	High Sand Liner 225 ID Round Product xxx * (BSRIA14199/1)	200mm Square Product (BSRIA 14566/1)	High Sand Liner 225 ID Round Product (BSRIA 14813/1 & 2)
	% Volume	% Volume	% Volume
Sand	27.5	4.6	19.4
Paste (cement)	19.5	34	34.4
Pumice		47	
Lytag/Ash	36	9.4	20.9
Ironstone			6.5
Void	17	5.0	18.9

* This product bore the same identifier as used for Chimney A of the CRE tests. It should also be noted that these analyses have wide error bars of +/-3 percentage points (minimum).

30. It is considered useful to note the apparent variation in the analysis of the 225mm round concrete flue liners. Thus the cement content (by volume) varies according to analysis from 19.5% (BSRIA xxx) to 24.7% (Chimney A) to 34.4% (BSRIA 14813, May 1999); the manufacturer states that the composition of these liners did not change. The possible error bars on the analyses are large +/-3%. As said above this conflicting data must raise the question as to whether the differences between the performance of the liners in the different experiments are due to the test procedures or the different liner compositions. In reality it may be a combination of both factors.

FIELD EVIDENCE OF DEFECTIVE CONCRETE FLUE LINERS

31. In order to substantiate the laboratory simulations described above, the information needs to be viewed in conjunction with field data. This is considered an essential step and without it, the fitness for purpose of any particular product is very difficult to judge.

Field data.

32. Considerable effort was expended trying to track down evidence of failure of concrete liners with a high sand content. The location of several estates with such liners was established, and specific enquiries were made of one estate known to have solid fuel appliances. No householder complaints could be identified. There was no evidence (that stood up to any scrutiny) that directly linked any of the concrete flue liners, of a high sand content, with any defective flue or poor performance. Installation problems seem relatively common, but these occur with every type of liner. Neither the NHBC nor Zurich reported any increase in the level of claims made with respect to chimneys. Anecdotes, circulating within the chimney industry and heard by members of the CRE Expert Group, regarding the poor performance of certain liners, could not be supported.

33. Perhaps a contributory factor to the discussion surrounding the performance of liners with a high sand content (and their fitness for purpose) was a claim made by their manufacturer that they were made from Refractory Concrete.

Others contested that this was not the case. Such matters of definition, whilst undeniably an important trade description matter, are not considered germane to this risk assessment.

House inspections.

34. The possibility of undertaking a series of individual house inspections was considered as a possible addition to this contract, but rejected by the DETR on practical grounds. To be meaningful a significant number of solid fuel installations would need to be visited where solid fuel stoves had been correctly connected to liners with a high sand content and the chimney should have been constructed to a good standard of workmanship. The operating regime of these appliances would also need to be known with a reasonable degree of confidence, and the householder would have to permit access to the roof with a video camera. Before the laboratory work at CRE Group was undertaken, the nature of likely failures was also unknown. The sum of these restrictions was considered unreasonable.

35. New evidence with regard to field service may be forthcoming. During the course of the investigation a possible location for a multiple dwelling survey has been established. Due to the known use of solid fuel on this site, the CRE Expert Group recommends such an exercise be carried out. Knowing the damage experienced by Chimney A, (paragraph 17) the investigational techniques could include both video inspection and smoke testing. If the liners were to appear physically damaged, then samples could be removed and the condition of the concrete assessed for macro- and micro-cracking. (see Paragraph 46 for a description of these different modes of cracking). Severe micro-cracking would indicate a much reduced service life.

FATALITIES ASSOCIATED WITH SOLID FUEL STOVES

36. The CRE Expert Group felt that the risk was not solely restricted to solid fuel stoves but does concur that if there were to be a problem with chimney liners, this would manifest itself more quickly and more severely over such appliances. This is because of the much higher flue gas temperatures that occur over a closed stove, mean temperatures of up to 450°C with peaks (shortly after refuel) up to 900°C. Mean flue gas temperatures from open solid fuel fires and gas fired appliances rarely exceed 300°C and are usually much lower.

Deaths from solid fuel appliances.

37. In 1998, deaths from solid fuel (26 total, but nearly all from closed appliances) were very similar to deaths from natural gas (25). An analysis of deaths and "near misses" from solid fuel since 1995 is given in Appendix C. To summarise this data with regard to fatalities the condition of the flue was regarded as a primary factor in 35% of incidents. This figure rose to 58% of incidents when the condition of the flue was considered either a primary or secondary cause. With regard to "near misses" the corresponding values are 33% and 47% respectively. 60% of fatalities involved appliances with conventional close fitting "throat plates". These "throat plates" are horizontal iron baffles located in close proximity to the flue outlet of many UK stoves and roomheaters; they are used to prevent the direct exit of flue gas from fuel bed to flue and hence increase the thermal efficiency of the appliance.

38. Although the number of deaths from natural gas and solid fuel appliances is similar, those from the latter arise from a much smaller number of installations (about 730,000). The incidence of death from gas appliances in the UK is thus approximately 1 per million appliances per year, this compares favourably with the incidence of death from a closed stove burning solid fuel of approximately 1 in 30,000 per year. For comparison the risk of poisoning from a solid fuel open fire is similar to or less than for gas. The reason for this is that the by-products of solid fuel combustion will cause deposit formation, which lead to the risk of flue or appliance blockage. This is the principal reason for the difference in safety record of solid fuel appliance when compared to that of gas.

39. The principal hazard from a defective chimney over a solid fuel appliance is from combustion gases spilling into the living quarters causing fires or accumulations of toxic gas. Coincidentally not only are the flue gases from a solid fuel stove likely to be hot (compared to a natural gas appliance) but the combustion gases from closed solid fuel appliances are also very dangerous. The carbon monoxide (CO) content of flue gases from a solid fuel stove, when operating correctly, can easily be 5000 to 10000ppm. This compares with 200 to 300ppm from a modern gas appliance. For comparison the 8 hour exposure limit to CO in industry is 50ppm This picture of the relatively high number of deaths from CO poisoning from solid fuel stoves is reflected in France, Belgium and to an extent Germany (Reference Consumer Safety Research, Carbon Monoxide Poisoning (Europe), DTI, January 1995).

MECHANISMS BY WHICH A DEFECTIVE CHIMNEY CAN CAUSE COMBUSTION GASES EMISSIONS

40. The possible risks associated with defective chimney liners include increased risk of fire spreading to the house, mechanical collapse and leakage of combustion gases to the dwelling or a neighbouring attached dwelling. The toxic combustion gases leakage is considered the most serious problem. Data from the insurance industry (Zurich Insurance) indicates no statistically significant current problem with house fires arising from masonry chimneys.

41. Defective flue liners can allow emission of combustion gases into the living space by means of:-

- The existence of a hole in the flue wall sufficient enough to allow combustion gases to pass out. This assumes that the flue is not under negative pressure conditions at this point.
- Material from the liner falling from the chimney as dust or large pieces and blocking the outlet of the appliance, forcing leakage of combustion gases from the appliance itself.
- Complete collapse of the liner leading to severe restriction of the flue and simultaneous creation of a large hole, through which flue gases could escape. This scenario would give most cause for concern.
- Large cracks that allow such a high level of air ingress that the draught is effectively destroyed and the chimney no longer removes product of combustion from an appliance.
- Cracks of sufficient size to allow air ingress to chill the flue gases.

Primary effect of air leakage into chimneys.

42. The direct effect of large leaks is to reduce the driving force that lifts the flue gases up the chimney. If the latter leaks, the air ingress chills the flue gases thus increasing their density, reducing their buoyancy and weakening the draught.

43. All closed stoves have an “overfire air system” to provide additional air over the firebed to burn-off excessive levels of CO; if the draught is weakened sufficiently the appliance, instead of drawing air in through this “overfire air system” can then start to spill combustion gases (backwards) from this system. This combustion gases will have a high CO content, and hence this is a highly dangerous occurrence. This is particularly likely to occur at night when the appliance is only slumbering because this is when the draught within the flue is at its weakest.

Secondary effect of air leakage into chimneys.

44. Although not an immediate cause of combustion gases leakage into the living space, the chilling of flue gases (by air in-leakage) also causes an extremely important secondary effect. In the case of solid fuel combustion this chilling promotes the condensation of tars and soot. These deposit on the chimney walls causing a restriction and reduced draught and an enhanced risk of chimney fire. Furthermore these deposits pose a finite risk of spontaneously dislodging and falling down the flue causing a blockage at any bend, or in the appliance connection pipe, or on the appliance throat plate. Such a spontaneous fall is often associated with heavy rain. A leaking chimney is thus more prone to blockage, requires more frequent sweeping and produces less effective draught at the appliance connection. All of these accumulate to increase the risk of combustion gases entering the living space.

THE DEFINITION OF A DANGEROUS CHIMNEY

General condition of chimneys.

45. It must be said that a large number of chimneys in everyday use have cracked flue liners, although the flue continues to operate satisfactorily, and some will show no leakage during a smoke test. Good quality liners will crack, for instance, during an intense chimney fire; this however relieves the pressures building up within the liner and stops worse cracking at a micro level. The concrete industry identifies at least two distinct modes of failure. Micro-cracking where the bonds between the cement paste and the individual aggregate particles become weakened and the material gradually powders; and macro-cracking where an otherwise satisfactory component breaks into large segments, typically several centimetres across. Both are problematic although severe micro-cracking is generally regarded as more serious, as the whole material may eventually loose its strength. In contrast macro-cracking of large components maybe a manifestation of a stress induced during manufacture and no more deterioration may occur. After a chimney fire such liners suffering only macro-cracking are unlikely to deteriorate further.

46. The air leakage from cracks must also be put into perspective relative to possible leakages from joint seals, which over a period of years are likely to fail. In this context the minimisation of joint seals (for example by the use of longer flue liners) is generally to be recommended.

The “acceptable” condition of a chimney.

47. The building and installation trade currently determines the level of acceptability based upon a tradesman’s judgement. This judgement is based upon the leakage (if any) seen during a smoke test to BS6461. Such leakage could be quantified using appropriate portable equipment for the whole chimney and expressed as litres/sec/m^2 of inside chimney area. This quantitative approach is increasingly used within continental Europe. Although providing useful information as to the condition of a flue the CRE Expert Group would be cautious about relying too heavily upon such a leakage figure, as it could be associated with one large hole.

48. The usual concept of “acceptable” leak through the wall of a flue liner into a masonry chimney, is where:-

- The air in-leakage does not significantly add to the volume of gases flowing up the chimney.
- Small cracks are in a zone always under sufficiently negative pressure so as to prevent flow of combustion gases out of the chimney.

49. Conversely, cracks which might arise further up the chimney where the pressure difference may become minimal, or even reversed (i.e. inside the chimney has a higher pressure than outside), could be very serious.

50. It is difficult to assess at what level a defect within a chimney presents an unacceptable level of risk of an incident occurring. It is proposed that a defect becomes unacceptable whenever it allows combustion gases to enter the property. This is irrespective of wind effects etc.

51. It is because of the complexity of the situation, in particular the acceptable degree of smoke leakage permissible that the CRE Expert Group recommend that ‘competent persons’, who have received appropriate training, should make the judgements as to fitness for purpose of a chimney. A more accurate definition of such fitness would also be useful.

52. It might be thought that by “perfect” construction of a flue any risk of combustion gases emission to a room would be eliminated. The CRE Expert Group believes such a view unhelpful. No masonry chimney can be constructed to a sufficiently high standard to ensure that blockage of the flue would not result in some leakage. The materials themselves are often porous and large masonry structures (subject to thermal cycling) inevitably deteriorate crack and move with age and use. It is erroneous to think that continuous striving to increase flue gas tightness (above a reasonable level to be discussed below) can eliminate the combustion gases emission to the dwelling in the absence of correct operation and maintenance.

The identification of damaged chimneys.

53. A point of concern expressed by some members of the CRE Expert Group was that concrete liners of the types tested at CRE had suffered considerable loss of strength at the micro scale. They were thus more likely to crumble and fall down the chimney during any sweeping process than (for example) clay liners where the material itself generally remained strong and cracking was restricted to stress relief at the macro scale. In a significant number of fatalities, evidence of pargetting or liner fragments has been found in the

debris blocking the flue. Because of the risk of damage to any flue from chimney fires, ammonium salt attack, or other unusual deposits, the householder must perforce rely upon competent and professionally registered sweeps to report such conditions to the householder and arrange an appropriate repair. The CRE Expert Group considers that reporting on the condition of a flue should be an essential part of a sweep's role.

AN ESTIMATION OF THE RISK OF FATALITIES

54. Using the laboratory data, generic data on incidents from the field, (referenced from the SFA reports, Appendix C) and information from manufacturers, we have commissioned Watson Wyatt to carry out a risk assessment for concrete chimney liners, details of which are given in Appendix A. Discussions with the manufacturer of liners with a high sand content indicated that sales of products similar to that tested in Chimney A amounted to between 40,000 and 50,000 chimneys and that up to 3000 could be installed over solid fuel stoves. The CRE Expert Group would agree that the number of solid fuel stove installations associated with the total number of liners sold is not unreasonable.

The national incidence of damaged flue liners.

55. In particular the risk of CO poisoning associated with liners with a high sand content has been investigated. As reported above no evidence could be found from the field of problems with liners of a high sand content. In fact little numerical data could be identified on the condition of any lined flues; an exception to this was information from a heating services contractor who had data for principally northern coal mining areas and indicated that when inspecting rented property with liners after an interval of about 15 years, between 5 and 10%, would have cracked liners within about 1m of the fluepipe entry. Typically, 2/3rds of the latter would then fail a full smoke test, and 2% (of the original 100 properties) might show some evidence of combustion gases spillage into the property. Whilst applicable for rented urban property burning smokeless fuel, anecdotal evidence indicates higher percentages of cracked liners in rural areas with a high incidence of chimney fires. Many householders report hearing loud cracking noises during chimney fires. Despite hearing this cracking, unfortunately many householders merely attempt to clean the chimney themselves or without fully briefing the sweep. The chimney would therefore not be properly inspected after a fire. Many householders will also not call for an inspection, unless there is clear evidence of combustion gases spillages into the house.

The risk associated with 3000 liners of a high sand content.

56. On the basis of their experience as actuaries, and their general experience of risk, Watson Wyatt consider that the 3000 flues with high sand liners (Appendix A) could be ASSOCIATED WITH up to one additional death per year. It must be stressed that this value was tested using more than one approach, which broadly give the same number, but that in the absence of field reports the statistical base is weak. The major input criteria were the incidents of fatalities with lined flues since 1995, the incidence of damaged liners in the general population (Paragraph 55) and the final condition of Chimney A. Some other members of the CRE Expert Group felt that there was insufficient data to accurately calculate the number of deaths per year, but agreed with the general approach of Watson Wyatt. It must be noted

that this is "ASSOCIATED WITH", not "CAUSED BY". This distinction is offered because a defective flue does not immediately cause combustion gases emissions but there is an extremely strong linkage between such defects and the emission of combustion gases by the mechanism described in paragraph 44. For this reason flue liners must maintain their integrity under all reasonable firing regimes. For the sake of comparison the death rate that would be expected to be associated with 3000 appliances connected to flues, in a sample selected to represent actual frequencies of lining materials, is between 0.11 and 0.16 deaths per year.

The scarcity of supporting field data.

57. Because of the scarcity of the statistical data, the CRE Expert Group recommend that a number of flues built of liners with a high sand content are inspected. The laboratory temperature profiles would indicate that the use of wood, or smokeless fuel would decrease the risk of liner failure, whereas operation with bituminous coal would increase the risk. The actual effect of burning such fuels, or mixtures of fuels, can only be obtained from reasonably extensive field tests ideally in more than one location, and both within and without a Smoke Control Area. If damage was severe appropriate action could be recommended; options could range from re-lining to rebuilding, depending upon the nature and extent of any damage. Such field data would also give data on any currently unforeseen problem that could raise risk levels in the future.

58. It should be noted that any carbon monoxide fatality is likely to be only the worst outcome of a much larger number of low level poisonings. No estimate has been possible of the level of ill health that could be caused before a leaking flue is identified as the correct cause.

Other factors contributing to the risk of an incident.

59. It must be noted that poor chimney condition is often only "a factor" in an incident. The appliance flue ways, flue pipe and chimney of any solid fuel appliance must be regularly cleaned and swept. To fail to carry out this function will inevitably result in leakage of combustion gases into the house with possible injury and death. Additionally the chimney must not terminate in a zone of low pressure and the appliance should have an adequate air supply.

Management and minimisation of the risks from chimney liners.

60. The CRE Expert Group does not wish to comment upon the acceptability of this level of risk, but we do believe that the risk is increased over what might be expected if Chimney A had completed the test work with the liner in good condition. It should also be pointed out that the material of construction of Chimney B did not perform well. The following generic improvements will benefit both present and future householders having any type of flue. The risk of any particular flue leaking into the house will increase as its age increases. We thus stress that managing the situation in the future is very important. This means:-

60.1 Ensuring that all chimney liners sold in the future are proven as fit for purpose, for example by having flue products certified by independent testing;

60.2 Ensuring they are correctly installed;

60.3 Ensuring that unacceptable products, either currently in use, or builders merchant stock, can be identified and appropriate remedial action taken;

60.4 Persuading householders that their chimneys should be swept by competent operatives who are briefed upon what to look for, and who will report defects to the householder;

60.5 Persuading householders they should keep the appliance clean and burn good quality fossil fuel, or well seasoned wood;

60.6 Improvements in the training of sweeps and installers, introduction of product identification, introduction of product monitoring and feed back system;

61. It must be stressed that sweeping a defective flue in no sense repairs it, but a clean flue no longer runs the risk of blockage by a soot fall (Paragraph 45) and spontaneous CO poisoning from a clean flue is very rare. Unfortunately, in practice it is difficult to keep a defective (i.e. leaking) flue clean.

The effect of the Kyoto Protocol.

62. The Kyoto Protocol is expected to promote a general move to higher efficiency appliances, such as the stoves and roomheaters used in our tests. These generally produce more arduous chimney conditions (both higher temperatures, greater risk of condensation at low output and higher levels of carbon monoxide) than traditional UK open appliances. This may be expected to increase the level of risk both of failure and subsequent poisoning from all types of chimney liner, including those with a high sand content, within their originally expected lifetime.

THE USE OF MATERIAL COMPOSITION TO SHOW COMPLIANCE WITH BUILDING REGULATIONS

63. One of the tasks of the CRE Expert Group was to comment upon the material of construction of the liners themselves. There was a specific brief to recommend maximum sand content. Historically, UK Building Regulations defined the acceptability of products for the construction of masonry chimneys by reference to British Standards or (in the absence of suitable British Standards) by listing materials of composition. With only a small number of manufacturers offering traditional products, and little or no foreign competition, this arrangement operated satisfactorily. However the trading situation has changed; UK competition has increased leading to greater product innovation and the Construction Products Directive is encouraging a free movement in building products. In light of this, continued reliance upon the historical approach would be imprudent. Unfortunately, until EN1857 is formally published there remains no authoritative product standard.

The historical definition of materials of construction.

64. Listing materials has always been rather imprecise. The accurate definition of natural materials is very difficult and liner shape (in particular profile) and the manufacturing process (especially water content) will significantly effect both short term and long term performance. It is understood that in early

discussions regarding the current European standards for liners, attempts were made to follow the route of defined material feedstock but it was eventually abandoned.

65. To discuss this in greater detail:-

65.1 Pumice - This includes a variety of washed and unwashed size grades from a number of sources with different chemical composition. It is unlikely they will have exactly similar pozzolanic action. Pozzolanic materials, although not cementitious in themselves, contain silica (and alumina) in a reactive form able to combine with lime (CaO) in the presence of water to form compounds with cementitious properties. In high temperature concretes this is useful as it is the thermal cycling of CaO between its hydrated form $Ca(OH)_2$ and dehydrated form CaO that can produce serious mechanical damage to the concrete at a microscopic level. CaO combined with a pozzolanic material does not cause these problems, hence the advantage of having pumice and fly ash in flue liners. A pozzolanic material may be either natural or artificial. The natural pozzolanas are mainly materials of volcanic origin but include some diatomaceous earths. Artificial pozzolanas include fly ash, burned clays, and shales.

65.2 Sand – This is essentially ground particles and can be sea, quarry, sharp, round, with or without iron oxide etc. Many grades are now known to markedly affect the performance of the resulting concrete.

65.3 Kiln Burnt Aggregate/Processed Ash from Solid Fuel Power Stations (LYTAG) – This can originate from a number of sources, with different coal ash inclusions and aggregate. These will inevitably give different properties to the final product, in particular its pozzolanic qualities may well change. LYTAG is a trade name frequently used (erroneously) to describe a very wide range of light aggregates from coal fired power stations. These aggregates are designed for many different purposes, and only certain variants are sufficiently stable for refractory applications.

66. In order to investigate the ability to predict the performance of concretes from material composition alone four different concrete coupons were cast and suspended within the two flues constructed as part of the CRE laboratory investigation. These were exposed to flue gas temperatures of up to 900°C. Details of compositions and the results are given in Appendix Biv. Although these results can be rationalised after the testwork, it is strongly suggested that the performance of these mixtures of materials cannot be predicted with any confidence. It is interesting to note that "Ordinary Portland cement (OPC) and washed "pit sand" had the highest initial strength and suffered less loss of strength than many of the other mixtures. This was not expected. A similar inability to predict the performance of liner composition is reported by a large UK liner manufacturer who had to undertake a very substantial R&D Programme to determine the optimum composition for a new product range. High Alumina Cement (HAC), OPC, Pumice, Building Sand, Kiln Burnt Aggregate and Quartzite were all tested. The results obtained were often unexpected.

67. From the above data the CRE Expert Group draws the conclusion that exploration of the sand content of liners with the objective of defining a

maximum value for acceptable performance is an impossible task. Chimney liner manufacturers were approached as required by the brief, but the information received was general, probably understandable on grounds of commercial confidentiality. Sand type, and cement content are but two vital elements in the production of a good liner. Attempting to delve into the detail of sand content alone would divert attention from the other factors that equally affect "fitness for purpose".

POSSIBLE AMENDMENTS TO APPROVED DOCUMENT J

68. It is the opinion of the CRE Expert Group that the complex picture arising from the above data, means it is not possible to identify "suitable" and "unsuitable" materials for chimney liners. It is further suggested that more flexible design and novel materials will exacerbate this situation. The latter may particularly arise from the growth of the material recycling industry in order to reduce the quarrying of virgin building materials. Germany for example uses crushed recycled brick in its chimney products.

The adoption of Type Testing.

69. The CRE Expert Group thus recommends a transition to guidance based on recognising products that have a "TYPE TEST APPROVAL", and are subject to 3rd party quality surveillance.

70. The degree of such Type Testing and subsequent manufacturing QA procedures will need to be agreed but it is suggested that it should be sufficient to continuously monitor and control the quality of products, and to ensure that any modifications to product are also suitably Type Tested.

71. A variety of Type Testing options are possible; a selection are given below:-

71.1 Testing to a suitable BS product standard (or range of standards) and production according to an ISO9000 or equivalent QA system. Such standards are not currently available. In view of the imminent voting upon the relevant EN standards this is currently not a viable consideration.

71.2 Agrément Certification, again with a suitable quality control system. This would take considerable effort. Again in view of the status of the relevant EN standards, this is currently inappropriate.

71.3 Type Testing to suitable European Standards and a quality control system as proposed under the Construction Products Directive. In light of the status of the EN standards this would appear the most attractive route, subject to certain safeguards. These are discussed further within Paragraph 75. PrEN1857 Concrete Flue Liners, is to be voted upon in early 2000, and could become a full EN1857 by the middle of that year. BS/EN1457(1999) Ceramic Flue Liners, is already in existence. In the event of this route being adopted, we agree that the level currently proposed in the European Mandate to CEN for chimney products would, if implemented be satisfactory i.e. Class 2+, inspection by a Notified Body under the Construction Products Directive. Notified Bodies should have a suitably high level of product knowledge. Certification of the manufacturers Factory Production Control should include both his paperwork system and the test equipment used to physically examine samples of chimney. Such test equipment should comply with the latest standard; it is envisaged this may be either located within the factory or at a suitable test house.

71.4 Testing to a regime included in an Annex to Building Regulations. This Annex could closely reflect current EN standards and draft standards but would have the advantage of being under the direct control of the UK DETR. Such a proposal would need to be communicated to other Member States in accordance with the Notification Directive. Undoubtedly this option could be regarded as a barrier to trade and discussions would need to be held with the EU Commission.

72. The CRE Expert Group suggests the adoption of European standards as the preferred route (i.e. the third option above), but subject to some limited testwork to ensure their applicability in an UK situation. This would be because:-

72.1 Since 1989 CEN TC166 has been developing European Standards for concrete, clay and metal chimney liners. These documents would appear to be an excellent basis for the introduction of a Type Test approval scheme for chimney products.

72.2 The majority of UK liner manufacturers have maintained an active interest in the progression of the proposed European standards and have already had some or all their products tested to European Standards and provisional European Standards.

Interpretation of European Standards to the UK situation.

73. The "BSI Task Committee B/506 Task Group" producing the Transition Guidance to European Chimney in support of Approved Document J is considering the recommendation that a solid fuel chimney should have the minimum designation under the European classification of T450, N2, S, D 3 (for a definition of these terms, refer to paragraph 5). It is reassuring to note that the 450°C is similar to the maximum time averaged flue gas temperature reported from chimneys A and B, even under mis-use conditions. Actual EN test temperatures would be higher. The aforementioned Task Group is considering whether to include the proposal that a temperature class of T300 would be reasonable for an open fire installation, but if included, would rely heavily on the clear labelling requirement being proposed for the next revision of ADJ, to avoid problems with possible 'change of use'. For the foreseeable future such a product in the market place,(i.e. a liner capable of only T300, but not T450 and whilst still being capable of offering soot fire resistance) seems unlikely.

74. It should be noted that this is only a minimum designation, the manufacturer of closed solid fuel stoves particularly of small heat output might wish to specify an N1 category especially for flues of large cross sectional area.

75. The CRE Expert Group gave some consideration to the necessity to confirm the applicability of prEN1857 to the UK situation. It is acknowledged that this prEN and its sister standards are based upon a vast amount of field data from across the whole of Europe and has lead the CEN Technical committee to consider that products that meet this standard are 'fit for purpose'. However the tests and proposed pass criteria are relatively newly formulated

by the CEN TC and they have no track record as applicable for UK Building Practices and UK fuels. Because of this, it would seem prudent to recommend a modest one-off research programme before committing the UK to the adoption of European Standards (and their reference within ADJ) when voting takes place next year. It is suggested that the CRE 10 day simulated heavy duty domestic firing trials should be repeated on several products that have passed the relevant prEN1857 standard. Detailed comparisons between the temperatures reach by a liner fired with a solid fuel stove and when fired with a hot gas generator under the EN test conditions could give very useful insight into the reasons for any difference in behaviour. In particular comparison could be made between rate of temperature rise of the flue gas and liner, the temperature gradient across the liner wall and absolute temperatures reached.

76. There are several differences between the UK and continental Europe that could effect the longevity of liners to the detriment of the UK. These include the greater usage of bituminous coal in the UK, short vertical flue pipes in the UK between the appliance and chimney, and several designs of physically smaller appliance due to the traditional UK "Builder's Opening". No damage is expected, but if it were seen, investigations could be initiated to discover why products known to perform well in mainland Europe did not survive in a typical UK installation. It is stressed that this is not to suggest that the CRE test is an alternative standard but that such work would be a very useful benchmark in a UK context – particularly with reference to installation procedures, and UK building practices. Appendix D considers the possible implications of the testwork carried out under this contract on prEN1857. It is stressed that these comments are offered in a positive fashion and it is believed that European Standards will be applicable perhaps with changes to UK installation techniques, or to the categories of compliance required.

UK chimney installation instructions.

77. The CRE Expert Group noted the very modest nature of the installation instructions supplied with some UK liners. Some offered virtually no guidance as to installation detail. This is usually a requirement of product certification, but because of the importance of these instructions it is suggested that Building Regulations be written in such a fashion as to re-enforce this requirement. These instructions must able to be readily understood by a designer, bricklayer or appliance installer, both in the office and on-site.

78. A suggested minimum content list for these installation instructions is offered below:-

78.1 For the designer, detailed instructions as to how to incorporate the product into the total chimney, including:-

a) Design calculations;
b) Detailed recommendations on backfilling between the liner and the masonry structure to include dimensions, materials, mixes etc;
c) Detailed instructions as to how to use the product in a typical UK situation.

78.2 For the builder, detailed instructions on how to handle and assemble the product on site;

78.3 Post construction tests required of the product.

79. The majority of members of the CRE Expert Group had first hand experience of poor quality of on-site construction of chimneys and endorse a concept of certificates of completion for flues according to prescribed format; these should be handed over to Building Control and the eventual owner.

Suggested rewording of ADJ.

80. If the DETR were to follow the route of adopting the appropriate European Standards, the following text is offered for inclusion with the ADJ.

"New chimneys should have masonry and liners made of materials suitable for the intended application. Ways of meeting the requirement would be to use bricks, medium weight concrete blocks or stone with suitable mortar joints and suitably supported and caulked liners. Liners should be independently certified as to comply with;

a) clay liners BS/EN1457 1999, and
b) concrete liners BS/EN1857 2000 (In anticipation of)

Design calculations and specification sheets showing the suitability of the flue for its intended use, as well as evidence of construction in accordance with manufacturers instructions should be available to Building Control. Particular attention should be paid to recommended backfill and ensuring sockets are uppermost to capture condensate. Bends and offsets should only be from purpose made components. Products should be sourced from manufacturers operating an on-going third party Quality Audit System.

These European standards require knowledge of the intended use of the chimney. Appendix xx offers a simplified guide as to appliance type and generic category of chimney".

81. It is recommended that a table offering suggested chimney liner category against appliance would be useful for builders, it is appreciated however that specific appliance manufacturers may require specific flue performance. Production of such a guide is considered outside the scope of this report. It is recommended that appliance manufacturers commence providing detailed information on the category of flue required by their stoves, boilers etc. This is necessary to ensure a safe transition to the new EN chimney designation.

82. It is understood that the CEN TC166 aim to put prEN1857 (the provisional standard) to formal vote for conversion to a European Standard (BS/EN1857) in late 1999. This is expected to result in the publication of EN1857 during mid 2000. The CRE Expert Group felt it useful to offer detailed comment on certain aspects of prEN1857. These are included within Appendix D These comments are not regarded as sufficiently fundamental as to cast doubt upon the functionality of the standard, but are offered to highlight possible areas for improvement, and further investigation.

ENSURING THE QUALITY OF CHIMNEYS IN THE DWELLING

83. As indicated above Type Testing of flue products is only one aspect of a total quality system; in future correct chimney components must be chosen according to duty and the workmanship during construction should be good. Long term feedback from the trade on the performance of installations would also be useful.

Workmanship and control of the construction process.

84. The CRE Expert Group believe that a significant number of chimney problems and combustion gases emission arise from poor installation, and thus welcome the requirements within the latest proposed Revision of Approved Document J for builders to provide a "A certificate for checking and testing hearths, fireplaces, flues and chimneys". This should address issues such as:-

84.1 General quality of workmanship;

84.2 Compliance with all aspects of manufacturer's installation instructions, especially

84.3 Correct location and orientation of liners.

85. The CRE Expert Group considers a much more effective registration scheme for chimney constructors, solid fuel appliance installers and sweeps to be highly desirable. It further suggests consideration be given to making membership of such schemes compulsory before undertaking work on a commercial basis. The National Association of Chimney Sweeps operates such a scheme but it is not well known to the general public and is not supported by many members of the trade. It is hoped the forthcoming consultations on Competent Firms will take this forward.

86. A simple qualification for building site foremen in the construction of masonry flues could also be advantageous.

87. The introduction of European Standards will require major educational campaign for the chimney industry and such a registration scheme could be a useful vehicle for raising the quality of installation.

A professional body for sweeps and chimney constructors.

88. It is recommended that an organisation is chosen to act as a co-ordinating body with respects to all aspects of chimneys for the solid fuel industry in a similar fashion to the operation of CORGI in the gas industry. This body could carry out the following activities:

88.1 Train chimney sweeps, installers and (to a lesser extent) builders to recognise substandard performance of chimney components. This could be by training courses and distance learning packages.

88.2 Oversee assessment of competence of operatives. It is envisaged this would be in association with an accredited personnel certification organisation.

88.3 To raise the awareness within the industry of the need to improve standards and adopt new technology in an appropriate fashion. This could be by articles in an in-house newsletter or magazine (see also paragraph 87).

88.4 Operate as a repository of knowledge to both accept reports of defects and offer on-line advice on how they should be addressed. Companies should show a willingness (or if necessary be required) to notify significant problem installations to this body.

88.5 Publish an annual report containing quantitative data on chimney performance. Discussions could be held with a Solid Fuel Association on how their incident statistics could be used in this context.

89. Bodies that could operate such a scheme include the CORGI, NACS (who already have many of these arrangements in place) or the SFA. In the medium term the independence and stature of HETAS would seem to make it well fitted to perform this role.

90. The CRE Expert Group encourages the DETR to offer assistance to the setting up of such a scheme.

91. The CRE Expert Group notes with interest the compulsory annual inspection of chimneys in France. This is achieved via building insurance. This is not currently being recommended, on grounds of a suspected absence of public acceptability, although it could be adopted if the voluntary schemes for product feedback were found unsatisfactory.

92. As a result of the debate in the CRE Expert Group made during the course of this contract, it is clear that several types of out dated prefabricated and system flues installed between 30 and 40 years ago have effectively reached the end of their lives. Such information would be ideal candidates for the information dissemination of the programme recommended elsewhere (Paragraph 88.3).

An industry consensus on the design life of chimneys.

93. The CRE Expert Group notes that the risk of combustion gases emission from a flue increases as the flue approaches the end of its service life. Because of the nature of its duties, its mechanical condition and/or it failing a smoke test usually judge the service life of a flue. Thus during the life of a building the fewer occasions a flue has to be replaced (i.e. the longer the life of the flue) the lower the inherent risk to the occupants. Hence if a building is expected to last 100 years, a flue with a 15 year life would require replacement about six times, whereas if the life were 50 years replacement would be only once. Thus occupancy of the building with the longer life product must offer less overall risk to the occupants. Against this background it is suggested an industry wide consensus should be reached as to a recommended product life for new masonry chimney products. Following agreement the figure should be widely promoted. It might be hoped this would encourage builders to purchase on quality and longevity as well as price.

CONCLUSIONS

Field evidence.

94. No field evidence could be identified of particular problems with liners of high sand content, or any other particular brand. Neither the NHBC nor Zurich have reported any increase in complaints arising from defective chimneys during the time that high sand content liners have been in use.

Improving the level of professional knowledge within the chimney industry.

95. Poor on site construction of chimneys and inadequate maintenance by householders are considered by many a more serious problem than component specification. Certificates of completion for chimneys should also improve the quality of workmanship. Many sweeps and others associated with the solid fuel industry work in isolation with little training or up dating on current problems. This means that many generic problems are not addressed as quickly as possible. The National Association of Chimney Sweeps and HETAS operate registration schemes but these currently have a low profile with the general public. The DETR is encouraged to assist in the establishment of such a scheme.

Carbon monoxide, the principal hazard.

96. The main hazard arising from defective chimney liners is carbon monoxide poisoning. In some cases this can be by direct out-leakage but much more commonly by air inleakage into a flue promoting increased deposits and reduced draft. If not swept regularly this can then subsequently lead to blockage and carbon monoxide spillage.

The performance of two chimneys during a simulated domestic test.

97. It has been established that a brand of liner with a high sand content failed (by a significant margin) to pass the requirements of prEN1857. Whilst a legitimate subject for discussion it must be said that this does not prove such a liner as not fit for purpose in the absence of any supporting data as to the condition of such flue liners in the field. It was because of this absence of data that two UK brands of flue liner (one with high sand content) were installed within the lowest section of two separate chimneys, and test fired to simulate domestic conditions, which included a severe but nevertheless common challenge. Both would have required significant repair before they could be regarded as fit for purpose, although neither leaked combustion gases into the laboratory. Both flue liners suffered substantial damage to their concrete both at a microscopic and macroscopic level. The damage to the high sand liner installed within the insulated chimney was generally more severe. Because of the level of damage to the high sand liner, which was suffered within a relatively short period, an examination of the performance of these flues in the field (at both a macro and microscopic level) has been strongly recommended. In a separate test two brands of OPC/Pumice and HAC/Pumice cracked during a simulated chimney fire.

Other test work.

98. Twelve cyclic tests of an insulated chimney made with high sand content liners (carried out by BSRIA) showed no damage. Whilst interesting the chimney was fired using an indirect natural gas burner; and for a given flue gas temperature this is known to give lower rates of radiant heat transfer to

the liner; and such lower radiance has in the past been shown to give less damage. Thus this testwork should not be used as a reason to defer carrying out field investigations of the condition of high sand liners.

The composition of flue liners.

99. The assessment of the sand content of liners with the objective of defining a maximum value for acceptable performance is considered an impossible task. Sand type, and cement content are but two vital elements in the production of a good liner. Attempting to delve into the detail of sand content alone would divert attention from the other factors, for example other constituents, shape and manufacturing technique that may equally affect "fitness for purpose".

Advice required on backfill.

100. The backfill (if present) between the liner and the chimney plays a key role in establishing the operating temperature of the liner, and the compressibility of the backfill defines how much thermal movement is transferred from the liner directly to the structure of the chimney and thus the degree to which cracking of the chimney and any external rendering occurs. The CRE Group believe that the liner manufacturers must offer firm guidance on these matters within their instructions. Inevitably different liners can be expected to have different requirements. For example the very porous nature of LECA or LYTAG backfill is clearly not appreciated by many in the chimney trade; such backfill will offer no significant resistance to leakage either into or out of the liner.

The possible risks from liners with a high sand content.

101. We believe there are between 40,000 and 50,000 chimneys comprising of high sand content liners in the UK, of which about are 3000 serve solid fuel stoves. We believe solid fuel stoves offer the greatest risk to householder because of the high flue liner gas temperature and high carbon monoxide of the flue gases. An independent risk assessment indicates these 3000 liners could be associated with between zero and one additional death per year. The actual number of incidents will depend very largely upon the degree to which householders sweep their chimneys and maintain their appliances. Such good practice, by householders and sweeps, does not repair a defective flue but will substantially reduce the risk of soot falls that can give rise to the risk of Carbon Monoxide poisoning. The CRE Expert Group is not in a position to comment upon the acceptability of this risk, but again recommends further investigation to identify the current condition of a sample of these liners in the field. Such field data would also give data on any currently unforeseen problem that could raise risk levels in the future.

Flues serving appliances other than solid fuel stoves.

102. Flues serving other types of solid fuel appliances and appliances burning other fuels may also be at some additional risk but we have concentrated upon solid fuel stoves as a litmus test. If the additional risks for solid fuel stove installations are small, then reassurance for other types is also provided. If the additional risks are shown to be real and substantial this would tend to question to safety of other types of installation, but lower flue temperatures and radiant flames restricted to within the appliance are expected to reduce the problem.

The likely effect of the Kyoto protocol.

103. Looking to the future, pressure to raise the overall thermal efficiency of fuel use in the home will tend to increase the use of closed appliances. In the majority of designs these have higher flue gas temperatures than open appliances, and hence subject the chimney to greater thermal stress. This would lead to caution against the building trade installing chimneys only designed for open fires unless such chimneys are plainly and indelibly marked as only suitable for a limited range of combustion equipment.

Type Testing.

104. A wide range of data is available on the performance of concrete at elevated temperature, however it would appear impossible to make reliable predictions based upon this information for the performance of concrete flue liners in masonry chimneys in domestic property. The CRE Expert Group suspects much of this arises from the difficulty in accurately defining natural products, certainly in the context of the highly competitive nature of the European flue and chimney market. This leads to the conclusion that in practice it is impossible to reliably predict the performance of flue liners based upon material composition alone. The preferred route for Approved Document J is then Type Testing and independent third party quality assurance. In view of the existence of a BS/EN1457 for clay chimney liners and the likely issue of BS/EN1857 for concrete flue liners in mid 2000 the CRE Expert Group suggest the use of European Standards as the basis for such Type Testing. Many UK and other European manufacturers are already testing against such standards on a voluntary basis. Such Type Testing (although now conceptually demonstrated for a huge range of products) is still not formally proven for flue liners in a UK situation hence the suggestion to carry out a short quantitative verification program between the European standards and UK Building practice.

The necessity to Type Test all chimney liners.

105. Although not the subject of this enquiry, it is clear that the microscopic damage to the HAC/Kiln burnt aggregate liner used within Chimney B is substantial. Abundant micro-cracking of the aggregate paste and aggregate paste interface near the inner surface of the flue was reported. Although reports of deficient performance have not been received from the field, this is considered to be a further reason why all UK liners should be Type Tested prior to their continued use.

106. For completeness and ease of reference the results of the CRE Expert Group activities in relation to each of the original DETR requirements is given below.

Detailed Requirements of the DETR and Summary of Results

DETR REMIT	RESULTS	Para

To use existing evidence and information from the four manufacturers and importers in the UK to establish composition of flue liners already installed;	Manufacturers were contacted, their replies were generic and insufficiently detailed to be of quantitative assistance to the contract.	67
To collate and appraise the results of the tests on flue components carried out by the various parties;	The relationship between failure during a test and poor performance in the field could not be proven; in a continental European context, liners that have complied with prEN1857 have been shown to give acceptable performance.	24 – 35 & 77
Drawing upon expert advice both in the UK and abroad, and from the experience of house builders and housing warranty providers to establish whether there is a threshold proportion of sand in concrete designs above which the performance of a flue liner made from such concrete is likely to be jeopardised;	Generic descriptors such as sand content cannot be considered meaningful. Firstly because sand content is only one factor in the performance of a liner and others such as cement content, voidage and manufacturing technique are equally if not more important. Secondly, it is difficult to define 'sand'.	64 & after
To establish how likely chimneys and flues are to fail, in what way, and in what circumstances, and in particular if the performance of concrete flue liners significantly compromises the performance of chimneys;	This has been answered in the detail of the report.	41
To establish what the consequences of failure would be, including the risk to the health and safety of the house occupants having regard to parameters such as chimney height, flue shape and size and type of fireplace served;	A detailed report has been prepared on deaths and near misses; this has lead to the production of a full risk assessment by Watson Wyatt (see below)	App. A
If the outcome of the above demonstrates that a problem may exist, to establish how many potentially unsafe liners have been installed and where they are;	The number of liners installed has been estimated and a possible number of "associated deaths" evaluated by Watson Wyatt. Poor performance shown by a laboratory test has not been confirmed by field evidence. Inspection of properties known to contain high sand liners would enable this figure to be evaluated. This is outside of the remit of this contract.	57

If found to be necessary, to make recommendations as to the advice that should be given to householders who may have defective flues and how this might best be conveyed;	Detailed advice would have to be based on field evidence, which is not available at present. In the meantime a more generic approach regarding the necessity to sweep the flues of solid fuel stoves and educate chimney sweeps is recommended.	60
To seek national and international expert technical opinion (and in particular from those developing relevant standards) on the ways that requirements of the Building Regulations can be expressed as quantifiable flue component performance standards;	Recommendations have been offered upon the use of Type Testing to appropriate EN standards.	69 & after
To advise on whether the guidance in the Approved Document to Part J of the Building Regulations (which is currently under revision) should be amended to address this issue for future building work. Particular issues, which need to be addressed, are whether the test procedures and performance classes in prEN1857 are satisfactory for UK Building Regulations purposes, or whether alternative tests need to be developed.	Recommended text to be incorporated within the ADJ has been offered. This suggests the use of EN standards but a short experimental programme is also recommended to demonstrate the applicability of this standard to the UK situation.	80

RECOMMENDATIONS

Type Testing.

1. It is recommended that the UK change over from flue liners being approved upon “materials of composition”, to being approved on their compliance with European Type Tests (Paragraph 72). This entails modification to Approved Document J (Paragraph 80).

Third party inspection of the production of flue liners.

2. If recommendation 1 (above) is adopted, it is further recommended that a third party should carry out such Type Tests and subsequent certification. The suggested standard for concrete flue liners is EN1857. Such products should be manufactured under a recognised third party quality assurance scheme. This should be as a minimum to EU/CPD Attestation of Conformity “2+”(Paragraph 71.3).

Further examination of high sand content liners in the field.

3. It is recommended that further field examination of the condition of liners with a high sand content is carried out in a full range of situations, as a minimum by internal camera and smoke tests. The location of a number of liners has been identified but a scientifically and statistically valid work program still needs to be established based upon the usage within particular houses. If a

significant number of defective flues were found, a remedial action plan would need to be generated. This is now viable as the experimental Programme at CRE (Chimney A) has given useful information as to the likely nature of any damage. (Paragraph 35).

Confirmation of the applicability of European standards to the UK.

4. It is recommended that a short research Programme is carried out to confirm the applicability of the standards laid down with prEN1857 to the UK situation. It is further suggested that several clauses within prEN receive further detailed consideration in light of the experimental data obtained during this Programme. In particular the abrasion test is considered worthy of further investigation.(Paragraph 75 and Appendix D).

Adoption of European standards in the UK.

5. It is recommended that a table offering suggesting EN chimney liner category against appliance would be useful for builders, and that such table should be included with Approved Document J. It is appreciated however that specific appliance manufacturers may require specific flue performance. Production of such a guide is considered outside the scope of this report. It is recommended that appliance manufacturers commence providing detailed information on the category of flue required by their stoves, boilers etc. This is necessary to ensure a safe transition to the new EN chimney designation. (Paragraph 81).

Minimisation of Joint Seals.

6. It is recommended that joint seals are minimised, for example by the use of long flue liners. (Paragraph 46).

Detailed installation instructions.

7. It is recommended that Approved Document J is amended to encourage builders to demand and chimney manufacturers to produce detailed installation instructions, that these include, how their product should be incorporated into the structure of the property, e.g. requirements for backfill (if any). These instructions should be available on-site during construction as well as to the designer. The Construction Products Regulations may eventually achieve this, but until this occurs it is recommend that Approved Document J should include guidance on this. (Paragraph 77).

Completion certificates for chimneys.

8. It is recommended that the proposed voluntary completion certificate for flues should be made compulsory. This was included in the draft new edition of the Approved Document J offered for consultation (Winter 1997/98). These completed certificates should then be supplied to building control bodies and building owners. (Paragraph 84).

Competent persons within the chimney industry.

9. It is recommended that the DETR should encourage an increase in the level of product knowledge and technical understanding in the building industry. A route to achieve this is via the registration as “Competent” of :-

- chimney constructors (site supervisors),
- solid fuel appliance installation trades people, via HETAS (and/or other bodies) and
- chimney sweeps, via NACS, HETAS (and/or other bodies) .

Such a professional register (or registers) can promote feedback from its members with regard to product information, chimney and flue defects, and how they may be initially avoided or subsequently rectified (i.e. remedial techniques etc.). Only ‘competent persons’, who have received appropriate training, should make the judgements as to fitness for purpose of a chimney. It is recommended that the DETR provide assistance in setting up such schemes. (Paragraph 60.4 and 88.2).

Problems with elderly prefabricated flues.

10. It is known that several types of pre-fabricated flue (installed 30 to 40 years ago) are reaching the end of their service lives, it is recommended that the DETR work with the professional bodies chosen under recommendation 9, to identify these flues and publicise the best solution to their replacement or repair. (Paragraph 89.3 – 92.

Development of a consensus on chimney design life.

11. It is recommended that an industry wide consensus be developed on a “reasonable” design life for chimneys. This is important as over (say) 100 years a long life product will inherently offer lower risk to the inhabitants than a short life product that theoretically requires regular replacement, and which in practice may see several years of operation in a sub-standard condition. (Paragraph 93).

Education of householders.

12. It is recommended that householders should be persuaded to only employ competent sweeps who are briefed upon what to look for, and who will report defects to the householder. Consideration should be given to making the reporting of such defects mandatory.(Paragraph 60.4, 60.5 & 53).

Regular servicing of the appliance and the use of quality fuel

13. It is recommended that householders should be persuaded to service the appliance regularly, and burn good quality fossil fuel, or well seasoned wood. (Paragraph 60.5).