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Fire Research Station

FIRE RESEARCH & DEVELOPMENT GROUP

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An Initial Review of the Fire Safety of Large Insulated Sandwich Panels

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AN INITIAL REVIEW OF THE FIRE SAFETY OF LARGE INSULATED SANDWICH PANELS

MANAGEMENT SUMMARY

This report presents the findings from an initial review of the fire safety of large insulated sandwich panels, carried out by the Fire Research Station under contract to the Fire Research and Development Group. These panels have been implicated in some recent fires and concerns have been expressed regarding the risks that they present both to occupants and fire fighters. The review seeks to identify the particular fire safety problems with large insulated sandwich panels by examining recent fire incidents and by visiting some selected working buildings which contain panels. Causes of fire vary from hot working to electrical sources, with a small number of deliberate ignitions. It would appear that the greatest risk of fire is in food process areas which are bounded by internal sandwich panel partitions.

Some laboratory tests have been carried out to examine the ignitability and general fire behaviour of the panels with a view to possibly more detailed and extensive tests later. It was intended that these experiments would include all of the common types of panel currently in use, but this was not possible since some types of panel are no longer in production and in the time available FRS was not able to locate any scrap panels of these types. In the event only panels with cores of polystyrene, fire retarded polyurethane and mineral wool were tested. All of the panels proved difficult to ignite and, once ignited, only the polystyrene core panel would sustain a fire. The tests indicated that only in exceptional circumstances are sandwich panels likely to be the item first ignited, however some types could contribute to an already severe fire.

The results of this initial review support the historical evidence that sandwich panels do not present a particularly high risk to the lives of the general public or to workers in factories containing sandwich panels: in other words, no greater risk than that from the other combustibles on the premises. However there is a clear unusual risk to fire fighters who may have to enter such a building on fire, since the fire can spread rapidly within some types of panel and the jointing systems will not prevent the steel sheets from falling away.

The risks from sandwich panels can be reduced by intelligent use of the panels and by sound fire safety management. It is hoped that this study will provide a basis for further coordinated research by government and industry.

CONTENTS

AN INITIAL REVIEW OF THE FIRE SAFETY OF LARGE INSULATED SANDWICH PANELS

1. INTRODUCTION AND BACKGROUND

1.1 Introduction

This report presents the findings from a short time-scale initial review of the fire safety of large insulated sandwich panels, carried out by the Fire Research Station (FRS) and commissioned by the Fire Research and Development Group of the Home Office. These panels have been implicated in some recent fires and concerns have been expressed regarding the risks that they present both to occupants and fire fighters. The review seeks to identify the particular fire safety problems with large insulated sandwich panels by examining recent fire incidents and by visiting some selected working buildings which contain panels. Of particular concern are panels used inside food processing factories and cold stores. Some laboratory tests have been carried out to examine the ignitability and general fire behaviour of the panels with a view to possibly more detailed and extensive tests later.

1.2 Background

For a number of years there has been growing concerns expressed by the public, the press and the fire world, especially the fire service, regarding the risks to life of occupants and fire fighters, and the risks of large property loss, from fires in large single storey buildings. The particular buildings identified are those commercial properties used for retail, light industrial, food processing or cold temperature warehousing. In the latter two cases the concerns were highlighted by the major fire at the Corbett Block, Sun Valley Poultry in Hereford in September 1993[1] where two fire-fighters died.

Investigation of the Hereford fire revealed that, in addition to the fire load provided by the contents, including chicken meat, polypropylene baskets, polyethylene film, polystyrene trays and other packaging materials, there was also a high fire load concealed within the large insulated sandwich panels used to partition the Corbett Block internally. These partitions were of the three main types currently available; ie non-combustible mineral wool, combustible expanded polystyrene and polyurethane. They were all steel faced and coated on the inner face to provide a food safe surface that could be frequently washed down with water sprays. (For day to day use, maintaining conditions in which food may be handled safely is the over-riding consideration for owners of such stores and factories. Fire safety is perceived as of lesser importance, if it is considered at all). The partition ceilings also created a large undivided roof void which was used to house a large amount of plant machinery, such as ventilation equipment. In the fire, the polystyrene-filled panels close to a large defrost unit were penetrated by flame at an early stage and fire spread undetected through the sandwich panel partitioning. Plant in the roof void fell onto this partitioning which collapsed onto the two fire fighters and impeded their rescue[1,2,3].

This fire, which was in an isolated building on an industrial site, received wide publicity and the use of such panels came under scrutiny by the fire community and the press. Large insulated sandwich panels have been used for many years for the external envelope of buildings and their facades and are rarely involved in fire. Such panels have also been widely used in cold stores where reliable temperature control is achieved with the polymer-filled types. However large insulated sandwich panels have also been used as internal partitions or linings without regard to the process being carried out within that space, in particular by the food processing industry. This casual use as partitions reflects a short term need to respond to changing requirements within a process area but may then result in complicated escape routes and voids in which fire may spread. Such sandwich panels have also been reported in hospitals and retail premises.

This has led a number of fire brigades to question the procedure of fighting fire inside such buildings since they believe that they may present an unacceptable risk to fire fighter safety. This approach clearly could have serious operational implications for brigades where it could conflict with the need for search and rescue.

Different sectors within the industry manufacturing, selling or using the various types of panel are well aware of the concerns and have prepared fire safety guidance, or are actively preparing guidance, which includes advice for users of sandwich panels[4,5,6]. But, until very recently, there appears to be little evidence of co-operation between the sectors of the industry since the market sectors are very competitive[7-10].

There are also concerns from the insurance industry that fires in buildings containing sandwich panels often result in the loss of the building[11,12]. Consequently the Loss Prevention Council has introduced fire performance criteria for panels[13,14]. The International Standards Organisation (ISO) is examining fire tests for sandwich panels and seeking to develop a large scale fire test[15], but, at the time of writing, the draft test has not reached a stage where it is ready for public comment.

Much of the concern that has been expressed publicly has naturally focused on the combustible nature of some types of sandwich panel. However, many industrial processes require large quantities of combustible materials to be available, for example packaging materials, and so the problem must be more complex than this. There is clearly a potential conflict between the need for fire safety and the requirement for a safe and hygienic environment for food handling. Currently the only fire safety requirement imposed on sandwich panels is that under the Building Regulations Approved Document B for the surfaces of the panels, "partitions", to meet defined classes in the surface spread of flame test[16]. Approved Document B[16] is currently being reviewed and the need to impose further controls on the use of combustible core sandwich panels is under consideration. A number of fires involving sandwich panels have been examined as part of the ongoing FRS fire investigation programme for DoE. Further work at FRS for DoE has been carried out recently to examine the Home Office fire statistics data base[17]. This work is not summarised here but has shown that the greater risks lie in food processing buildings rather than cold stores.

2. OBJECTIVES AND METHOD

Despite the activity described above, the particular fire safety problems associated with sandwich panels are far from clear. The Home Office (and DoE) have been requested to consider introducing controls by the fire service,(for example via the Fire Brigades Union[18,19]) and started by requesting information from fire brigades on their experiences involving panels. Following this, as indicated above, HO have asked FRS to carry out a preliminary review of the whole fire safety issue of sandwich panels so as to objectively inform future action, in particular further research.

The programme of work agreed was as follows;

1. Consult with fire brigades, examine case histories, to seek to identify the actual fire safety problems due to sandwich panels.

2. Examine some selected buildings to seek to identify fire safety problems associated with panels in operating buildings. Carry out a fire load audit.

3. Carry out laboratory tests to determine the ignitability and general fire behaviour (including the evolution of smoke) of different types of panels under radiant heat, and other heat sources, in undamaged and damaged condition. Examine response of joints, edge details and fixtures.

The research should include consideration of the different types of panel, and requires the involvement of representatives of the appropriate industry bodies. The research study was made public through the issuing of a

HO 'Dear Chief Officer letter''[20,21]. It was intended that this initial study should be carried to a quite short time scale.

This report seeks to identify the particular fire safety problems with large insulated sandwich panels by examining recent fire incidents and selected working buildings containing panels. The study concentrates on sandwich panels used inside buildings and primarily those in the food and cold-store industries. Some laboratory tests have been carried out to determine the ignitability and general fire behaviour of the panels.

This report summarises the three phases of research by the Fire Research Station into establishing the particular fire safety problems presented by large insulated sandwich panels.

The first phase has been to build up a database of the experiences of fire brigades concerning sandwich panels. It has been necessary to establish the actions that were being taken by the brigades to identify premises with sandwich panels and the success of those actions. It was also hoped to achieve an indication of the number of premises and the range of types of use of the premises involved. Of interest would be the source of ignition and how the panel came to be involved. The information assessed would be that obtained by HO via a FINDS request, from FRS fire investigation reports and by direct contact with fire brigade officers through FRS's existing network.

The second phase has been to visit selected buildings in the food process/cold store industry to seek to identify fire safety problems associated with panels in working buildings and to attempt to carry out a fire load audit. It was hoped that sources of ignition might be identified, and the more general fire risks associated with the industrial processes being conducted. Issues such as housekeeping and active fire protection measures would be included. Clearly it would not be possible to be sure of seeing all possible variants of panel use.

The third phase has been to carry out a series of laboratory tests to seek to determine the ignitability and general fire behaviour (including the evolution of smoke) of different types of panel under radiant heat, and other heat sources, in damaged and undamaged condition. This last phase has also addressed the response of joints, edge details, penetrations and fixtures.

For this initial review the findings have been presented as a series of issues for further discussion and research.

For the purposes of this report, unless stated otherwise, the generic term 'sandwich panel' is used to refer to those composite panels which are assembled in a factory. Those which are assembled or finished on site may have very similar characteristics but will be identified explicitly where appropriate.

The industry produces many types of sandwich panel but concerns have centred on those with metal skins containing one of the three main cores; generally 50mm to 200mm thick:

mineral wool - a non-combustible fibrous material,

expanded polystyrene - a thermoplastic material made from the styrene monomer expanded to form a cellular structure; typically pure white in colour, it softens and melts on heating often before ignition / extruded polystyrene foam is typically blue in colour (sold under the trade name of styrofoam),

polyurethane - a thermosetting material made by mixing two components, typically yellowish/brownish/pinkish in colour, which will char on heating and could undergo flaming combustion if sufficiently heated.

Other types, which appear to be less commonly used, are polyisocyanurate and phenolic composite foams[22]. Glass fibre is also used as an insulation.

As mentioned above, the site visits have been made to a small selection of buildings which are believed to represent the different types of common use to which the panels are put in the food and cold store industry. The actual buildings are not identified within this report since they have been used as generic examples only.

3. FIRE INCIDENTS INVOLVING LARGE INSULATED SANDWICH PANELS

3.1 Fire brigade comments and incident analysis

A questionnaire on the subject of sandwich panels was sent to all fire brigades by the Fire Service Inspectorate in October 1995 via a FINDS Computer Net Notice. The responses to this questionnaire were used as the starting point for the first phase of this project.

Twenty-two brigades responded to the questionnaire including one brigade whose covering letter had become detached from the form and therefore could not be identified. Telephone contact was made with existing FRS contacts in 20 of those brigades from which FRS had not received a response to the questionnaire. Seventeen of these supplied the information requested and three are expected to do so in the near future. All of the fires for which FRS fire investigation reports are available were included in this survey and so the FRS reports were used to supplement or add to the information from the brigades.

Therefore in total this report is based on the views expressed by 37 brigades of which four are Welsh brigades and one is Scottish. Annex 1 gives the list of responding brigades.

Twenty two brigades were actively seeking premises with sandwich panels by various means. The most common approach was to ask local stations to report on premises within their area. The local knowledge of retained firefighters was found particularly useful in this. They often work in food processing plants or cold stores.

Several brigades were liaising with, or seeking information from local Building Control Offices. Their experience to date has been a positive response from just over half of the Building Control Offices contacted. Their general belief was that the information received did not identify all the premises in the area.

Alternative approaches were reported by Northamptonshire Fire and Rescue Service, and Hereford and Worcester Fire Brigade. Northamptonshire has tasked an experienced fire prevention officer specifically to investigate premises which might use sandwich panels. So far 60 premises have been identified as containing sandwich panels and they have yet to review supermarkets, hospitals and other small possible users of sandwich panels.

Hereford and Worcester have liaised with the local authority Environmental Health Officers to identify cold stores and food processing plants. In conjunction with these Environmental Health Officers they drafted a Health and Safety questionnaire. This was sent by the Local Authority Environmental Health Offices to 101 commercial organisations who might use sandwich panels such as cold stores and food processing plants . The questionnaire was worded so that the use of sandwich panels, along with other potential fire hazards, were reported by the organisations. Seventy replies were received and these are now being studied. The exercise has now been extended to cover supermarkets and other possible small users of sandwich panels.

After a serious fire in a Yorkshire Pudding factory, Humberside Fire Brigade carried out a programme of inspection to establish the number of buildings with sandwich panels within their area. Following discussions with FRS prior to this current project, they had at FRS's request gathered additional information. The impressive computer printout they supplied covers food processing plants, cold stores, retail outlets, factories and office accommodation. For each premises it lists the core material of the sandwich panels, the use of the panels, how they are fixed and locked together, the area of panelling and the method of joint seal, and its history of fire calls.

At the other end of the scale two brigades were of the opinion that there were no buildings in their area using sandwich panels.

The rest, although not actively looking for sandwich panels, would record their presence if seen during a fire safety inspection or a 1(1)D inspection.

Several brigades either claimed not to have the resources to actively look for sandwich panels or believe that they had other problems which were in more urgent need of their attention.

The usual practice in brigades, once a premise had been identified as containing or possibly containing sandwich panels, is to carry out a fire safety inspection. The information gained from this is then passed to the operations wing who carry out a 1(1)D inspection. Some brigades have incorporated this into a larger risk assessment programme.

Most brigades report difficulties in establishing that the internal partitions are sandwich panels. Then identifying the core material is particularly seen as extremely difficult. One brigade commented that unless they could be otherwise satisfied by the owners it was assumed that the core material was polystyrene, which was seen generally as the most dangerous material.

There was also confusion within some brigades as to the difference between sandwich panels used for internal lining and partitioning, and foam insulation boards used for cladding of external walls or within the construction of external walls.

All brigades that have identified premises with sandwich panels have made that information available to fire crews in one form or another.

In many brigades the concern expressed regarding the behaviour of sandwich panels was part of a wider concern as to the behaviour of large single storey steel frame buildings. Unexpectedly rapid fire spread within these buildings leading to early collapse was seen as an increased risk to firefighters safety. Several fire officers were of the opinion that these structures required a change in the 'culture' of the British fire brigades. They did not feel that a fire in a building should be fought from within the building just because it was possible to enter. Some fire officers did suggest that greater priority should be given to venting the fire to release heat and smoke through the roof of the building.

In general most fire brigades were aware of the risks posed by sandwich panels and had taken steps to inform crews. This usually had taken the form of an operational Procedure Note. Some brigades had arranged training sessions on the subject and were looking for visual aids to use in that training.

Several watch commanders stated that in future they would not commit firefighters to a building known to contain sandwich panels if they were satisfied that the building was unoccupied.

A total of 21 incidents have been considered. Of these 10 are reports supplied with the responses to the Home Office Questionnaire on sandwich panels. Eight are the result of FRS telephone contact, and four incidents had been the subject of Fire Research Station visits.

3.2 Cold Store - Pontefract, West Yorkshire

The building was an extension to an existing cold store and was in the final stages of construction. Estimates by the fire brigade put it at being 90% complete. The construction was steel frame with profile steel exterior cladding. Within the building steel and polystyrene sandwich panels had been used to form cold store compartments. This building covered an area of 69m x 95 m and was single-storey with a service walkway in the roof space above the sandwich panels. The concrete floor was also insulated with extruded polystyrene under a cement screed.

At the time of the fire, 14.38 h on a Saturday, there was no one within the premises and the new construction was not secure. The fire is believed to have been deliberately started in building materials, slabs of polystyrene and sheets of plywood within the building.

When the brigade arrived all the new construction was involved in fire and flames had penetrated the roof. No attempt was made to enter the building. Fire also spread to the existing cold store. The total response was 10 pumps and 2 aerials. BA crews were required to work in the smoke from the fire. Since the fire was well developed when the brigade arrived, the rate of fire spread within the new extension is not known. However, they were unable to prevent the fire from spreading to involve both the extension and the existing building.

Both the new extension and the existing cold store were extensively damaged by fire and declared unsafe by council officials. Damping down was done after the demolition of the building had made it safe.

Eight spectators in an adjacent water park were taken to hospital suffering from smoke inhalation. They were not detained in hospital.

3.3 Cold Store, Gateway Estate, Crewe

This large 4-storey cold store was approximately 18 m high, of steel frame construction with single sheet profile steel cladding. All internal partitions were polystyrene and steel sandwich panels.

The fire was caused by an electrical fault in a cable hidden under the bottom edge of a sandwich panel. This cable supplied power to a door motor. The fire started on the first floor and spread to involve all parts of all four floors and the roof. The fire brigade were able to limit the damage to approximately an 8 m wide section of one side of the building. The fire was spread to the ground floor by flaming molten drops of polystyrene falling from the ceiling sandwich panels onto packaging on that floor.

The fire was detected by a smoke detector which signalled an alarm in the security control point. However, the guard was not convinced there was a fire and delayed calling the fire brigade and raising the alarm. However, there were no problems reported in the evacuation of the building.

This information was supplied by Cheshire Fire Brigade by telephone conversation with FRS.

3.4 Glass House - Hempnall, Norfolk

The premises consisted of two glass houses: No 1 - 140m x 65 m, and No 2 - 68m x 50 m. They were both of a steel frame construction clad with glass and sheet steel. Within glass house No 2 there was an area of 30m x 20 m used for cold storage and packaging. This area was constructed within the glass house using steel and expanded polystyrene sandwich panels. The firm grew strawberries and required temporary on-site cold storage of the product. The sandwich panels were used to form the cold store within the glass house.

The fire was discovered at 16.00 h on a Saturday afternoon. It is suspected that a flammable liquid was used to start the fire within the glass house. This was then able to spread into the cold store and packaging area via the sandwich panels. This area was fully involved in the fire when the brigade arrived and completely destroyed by the fire. However, the brigade was able to limit fire spread to this area of the glass house.

3.5 Creamery, Shropshire

This is a recent incident and a report was not available. The following details were from a telephone conversation with FRS.

At approximately 07.15 h a drier leaked a large quantity of oil into the bund that surrounded it. For reasons not yet reported to FRS, the oil ignited and the single storey brick building it was housed in became fully involved in fire. Fire then spread to an adjoining building which housed a drier producing skimmed milk. This building was approximately 15 m high and clad with polystyrene filled sandwich panels.

On arrival the brigade found that the evacuation of the building was complete and were able to fight the fire from outside the building. The brigade was able to save part of the building. They understand that the polystyrene was treated with fire retardant. However, it did produce a large volume of black smoke which was trapped in the valley.

3.6 Poultry Processing Factory - Wolverhampton

This was a single-storey building dating from the 50s or 60s. It was brick built with an asbestos cement roof. The eaves were 2.5 m high and the apex was 4 m high. The building was 50m x 20 m and was part of a complex of 20m x 100 m. Internally the wall linings, false ceiling and partitions were steel and 25 mm polystyrene sandwich panels. The part of the building involved in the fire was used only for the storage of packaging materials.

The first call to the brigade was at 06.11 h via a 999 call. On arrival they found the building well alight with flames through the roof. The asbestos roof panels were spalling explosively and thick black smoke was issuing from the two entrances. Since the brigade were satisfied that there were no persons within the building, no attempt was made to enter it. The fire was seen to be spreading rapidly and the ceiling and the wall sandwich panels were collapsing. However, even though the brigade fought this fire from outside it was necessary for firefighters to wear BA whilst working at the entrances to the building. The total response was 8 pumps to give the required BA support. The building was a total loss except for an office area that was protected from the fire by a plastered block work wall. The brigade used thermal imaging and remote temperature sensors to monitor the progress of the fire from outside the building.

3.7 Food Processing Factory - Aberdare, Mid Glamorgan

This factory was built around 1980 and occupied an area of 140m x 60 m. It was a single-storey building with a two-storey office and changing room section. The construction was steel frame with a double-skin steel cladding. There was mineral wool and glass fibre insulation between the two skins. Internal partitioning was by steel and plastic foam sandwich panels used to form compartments.

At 22.00 h a fire occurred in an extract duct over a fryer during a between shift clean-down period. The ducting was seen to be smoking and a CO_2 flooding system activated and the premises evacuated. From outside the building the duct above the roof could be seen to be red hot. On arrival the brigade committed a BA crew with CO_2 extinguishers to put out what appeared to be a small fire in fryer. This fryer was 6m x 4m x 4 m and almost totally surrounded by sandwich panels. Due to the extent of the damage and lack of information on the building detail the brigade were unable to identify these panels, but steel faced polystyrene panels were seen elsewhere in the building.

Smoke was seen issuing from the roof and another BA crew investigated. They found smoke layering in the roof cavity and flames near the duct. At this point the power failed and the production area filled with smoke and flames at a high level. The BA crews withdrew. From then on the fire was fought from outside the building.

Sixty per cent of the building was severely damaged with a collapse over 40 per cent of its area. The rest of the building was damaged by heat and smoke.

3.8 Food Processing Factory - Hull

The building where the fire started was a portal frame steel structure clad with steel sheet on the walls and roof. Its dimensions were 80m x 60 m by 9.75 m high and it was part of a much larger factory complex of interconnecting factory buildings. Internally the building walls were lined with 100 mm mineral wool or expanded polystyrene-cored steel sandwich panels. There was also a false ceiling constructed of 150 mm expanded polystyrene sandwich panels at a height of 8 m. Mineral wool and steel sandwich panels had been used between the production area and first floor offices.

The fire started in a 40 m travelling oven on a Yorkshire Pudding production line. Fires of this nature were not unusual, and the staff expected to extinguish it with a fire extinguisher. However, when this was not effective the alarm was raised by a break glass alarm point and the building evacuated within 12 -2 minutes. Two members of staff continued to fight the fire and remove burning trays. They only left when escorted from the building by the fire brigade. These two members of staff had been unaware that the fire was spreading in the sandwich panels above them while they were attempting to fight the fire.

The brigade were able to fight this fire from within the factory as well as around its perimeter, but had to withdraw and regroup at once. A small part of the factory which did not contain sandwich panels was saved. A liquid nitrogen tank was also prevented from becoming involved in the fire but 14 firefighters were taken to hospital after exposure to ammonia escaping from the cooling spirals of a chiller. The building where the fire started was totally destroyed in the fire along with 70 per cent of the rest of the factory complex[23].

3.9 Poultry Processing Factory - Hereford

The fire started in the defrost area of this factory, approximately 90 m^2. The construction was typical of a light industrial building, being blockwork in steel frame with external cladding of brick and ribbed steel and covered some 140m by 130m. The bay roofs were pitched, and double-skinned with steel sheet with mineral wool insulation between. Internally the building had been sub-divided using mineral wool, polyurethane or polystyrene-cored steel sandwich panels. A false ceiling had also been formed using sandwich panels creating a roof void of 4-5 m through which ran various services and plant.

The fire started in the radio frequency defrosting machine. A member of staff smelt smoke and called the maintenance staff. They attempted to approach and open the machine but the heat was too intense and flames were seen at the rear of the machine between it and the sandwich panel partition. The fire alarm to evacuate the building was activated and the fire brigade called.

On arrival the brigade found that the building had been completely evacuated and black smoke could be seen from various openings. BA crew entered the building and tackled the fire using first hosereels and then later a jet. As the sandwich panel ceilings started to collapse the brigade withdrew and fought the fire from outside the building. However, another BA crew had entered the building at door remote from the fire to reconnoitre an alternative approach to the fire. Soon after entry they radioed back that the building felt hot, but there were no flames to be seen and little smoke. Shortly after that they called for assistance. A BA crew which attempted to reach them heard a rumbling noise followed by the collapse of ceiling panels within the building. There was also an explosion of released Freon gas. It was four hours before the bodies of the two firefighters were recovered. Rescue attempts were hampered by the collapse of pipe work and sandwich panels.

All the interconnected areas of the factory building were severely damaged by fire. Most of the fire spread appears to have been via undivided roof void above the sandwich panel false ceiling and through the polymer-cored sandwich panels. The building continued to collapse slowly after the fire was extinguished[1].

3.10 Poultry Processing Factory - Abergavenny

The heat output of the defrost system in one of the blast freezers in this factory had been increased, but the running time for the system had not been reduced to compensate. This resulted in a build-up of more heat than necessary to defrost the freezer. Heat was passed by conduction into the suspended ceiling sandwich panels causing the polystyrene within them to decompose and produce large volumes of smoke. A smouldering fire resulted in the panels.

The suspended ceiling distorted and was in danger of collapse so brigade firefighters were withdrawn until the ceiling was supported with props. However, as even more smoke was produced it became necessary to completely remove the ceiling. Fortunately the brigade were able to control this smouldering fire before the sandwich panels became involved in flame.

3.11 Meat Pie Factory - Hereford

This was an old factory building in which steel/ polystyrene sandwich panels had been used for compartments. The fire started in a smoke room, approximately 4m x 4 m. There was a flashover and sandwich panels fell from the ceiling. As they fell they ruptured an airline causing the fire to spread rapidly. However, the fire brigade were able in this instance to contain the fire within the area where it started.

3.12 Meat Processing Plant - Milton Keynes

This building was used by two different organisations; one was involved in the production of beefburgers and the other in meat butchery. Internal divisions were created by the use of expanded polystyrene-cored sandwich panels including the separation between the two processes.

On the night of the fire a cleaner heard a noise coming from the workshops at around 22.10 h. He saw smoke coming from between the wall and the ceiling. All staff were evacuated and the brigade called. The fire was found to be within an external wall at high level behind the external flue stack serving a hot water boiler. The fire spread laterally within the building. Most firefighting took place outside the building since the internal structure of the building rapidly became unsafe.

The cause of the fire was either an electrical fault or heat from the boiler igniting paper on a nearby bench.

The building was a total loss.

3.13 Poultry Processing Factory - Uckfield, East Sussex

The building involved stood on a large site owned by one firm. The site included four factory buildings, a cold store, various sheds, offices and social facilities. The construction was of reinforced concrete frame with brick and block external walls. It had been extended using steel frame and sheet steel cladding construction. In total it was 100m x 45 m and was linked to a three-storey brick factory. Internally 50 mm steel and polystyrene sandwich panels had been used to subdivide the volume, and 150 mm steel and polystyrene sandwich panels had been used around chillers and freezers. These panels had also been used to form a ceiling with additional polystyrene insulation above the panels and on the internal surfaces of the roof. At 15.20 h an engineer discovered plastic trays burning in a walk-in oven. He was unable to close the door and left to call the fire brigade. He and another engineer attempted to re-enter the building but were prevented by thick smoke. The factory was not in production at the time so when the brigade arrived they were correctly informed that the building was unoccupied.

A BA crew entered the building with a hosereel but were forced to withdraw 2 minutes later when a flashover occurred in the vicinity of the oven. Other firefighters seeking alternative routes into the building were also forced to withdraw.

Fire then spread very rapidly, but the BA crews were able to re-enter with a main jet. A second jet was used when the fire broke through the roof. At the height of the fire 9 jets were in use by up to 16 BA firefighters within the building. The brigade were able to prevent the fire from spreading to the linked brick factory and were also able to save an office area within the factory. They were also required to cool a liquid nitrogen storage tank which suffered slight damage. Otherwise there was a varying level of fire damage to all the factory area with roof collapse over 60 per cent of it.

The investigation of the fire suggests that it was caused by faulty electrical equipment in the roof void above the walk-in oven. The plastic trays burning were probably ignited by burning drops from a polystyrene foam fire in the ceiling of that oven.

Working conditions for firefighters within the factory were extremely hazardous with the fire spreading rapidly within the roof void. Three firefighters suffered minor injury and were taken to hospital but not detained there.

3.14 Poultry Factory - Willend, Devon

The factory consisted of a single-storey processing and storage plant of 140m x 70 m. It was linked to cold stores and workshops. The construction was steel frame with steel and polystyrene used for external walls and internal partitions.

A cleaner noticed smoke at 01.25 h in a trussing area of the factory. She alerted all other members of staff who left the building.

On arrival the brigade found fire out through the roof above the plant room and within 15 minutes the fire had spread to involve all of the processing plant. It is believed that the fire was a result of an electrical fault and the spread was assisted by the presence of sandwich panels. The food processing plant was a total loss but the brigade prevented the fire from spreading to adjoining buildings.

3.15 Food Processing Factory - Broxbourne, West Lothian

This food processing factory, including chillers, covered an area of 140m x 70 m. It was part single-storey and part 2-storey. The structure was steel frame, mostly clad with steel but with some brick cladding. Internal compartments were constructed of steel and polystyrene sandwich panels. The fire was first seen by a security guard at approximately 03.24 h in one of the chillers. The brigade was called at that time.

On arrival the brigade entered the building in BA and went to and entered the chiller where the fire was reported. They found a fire at ground level which they extinguished with a CO_2 extinguisher. Flame was then seen at ceiling level and through failed joints between sandwich panels. Firefighters heard a fan start running in that area. This was followed by a rapid increase in fire severity, forcing them to retreat from the chiller. Fire was then seen on the outside wall of the chiller and a hopper was also seen to be alight with burning droplets falling from it. The fire brigade withdrew from the building as the fire continued to spread through voids above the sandwich panels causing some of them to collapse. The firefighters were showered with debris falling from the ceiling as they retreated. Fire then spread to involve all the building.

The brigade report that the rate of fire spread was increased by the action of a fan. They were unable to isolate the power supplies to that area to stop the fan running and enable water to be safely used on the fire. The quantities of black smoke produced required crews to wear BA while fighting this fire from outside the building.

The cause of the fire is believed to have been an electrical fault in a portable air scrubber used to reduce the fumes from a floor adhesive. However, it is also reported that sandwich panels were earlier damaged in the chiller when an evaporator overheated.

3.16 Abattoir - Buckingham

This building was a complete production process and included an abattoir, cold stores, meat packing lines and a small retail outlet. It was 150m x 120 m single-storey with a brick built 3-storey office block at one end. In general the structure was steel framed with a double-skin steel cladding on the roof and walls, with fibreglass insulation between the skins.

Internally, expanded polystyrene-cored steel sandwich panels had been used to sub-divide the volume to create freezers chillers and packaging areas. The fire occurred on a Saturday after the plant had closed at mid-day. Maintenance work had been carried out that morning including hot working on a conveyor belt in the boning and cutting area. It is believed that the belt was run before it was fully cooled.

The 35 staff that were on site were involved in a gas leak incident elsewhere on the site. However, one member of staff discovered the fire in the cutting and boning room. He used a break glass alarm point and left the building. A security guard also saw smoke from under the eaves and called the fire brigade. On arrival the fire brigade were unable to enter the building since the keys were not available. They had to cut a way in through the wall near the seat of the fire. One firefighter entered the building by this route but was prevented by the intensity of the fire from remaining inside. Estimated times from ignition to first call was 25 minutes, therefore the fire was well developed with some collapse of the roof when the brigade arrived. The fire was fought from the outside of the building.

Most of the building was damaged and demolition was in progress when the FRS team visited. At that time it was expected that only the office building could be saved. The burn pattern on the external walls indicated that the fire had spread at a high level in the void above the ceiling sandwich panels[24]. We understand that the whole site has now been cleared and there are no immediate plans to rebuild.

3.17 Plastics Components Factory - Clwyd

The fire involved external cladding of the building which was block work with an outer steel skin up to a height of 2.5 m with a double skin steel cladding above that and to the roof. There was polyurethane insulation between the inner and outer steel skins.

The fire started in skips and pallets next to the outer wall and spread into the insulation and interior of the building by conducted heat to the polyurethane between the steel skins and to stored packaging against the inside of the wall.

This incident did not involve sandwich panels as defined in this report but has been included to illustrate the problems of identification.

3.18 Rubber Mouldings Factory - Farnborough, Hampshire

This was a three-storey factory building, 31 m^2, which had been developed in five stages using various types of construction. The area involved in the fire spread was steel frame construction with profile steel and polystyrene sandwich panel external cladding above 2.4 m. The panel thickness was a maximum of 75 mm and a minimum of 35 mm. Internal cladding was Gyproc Fyreline board at ground floor and concrete block on first and second floors.

At approximately 21.30 h there were seven staff within the factory when a storeman saw smoke issuing from an open roller shutter door to a service area. He discovered a fire in packaging material under the stairs in that service area and could also see a fire in the next room, a mould cleaning room. He sounded the alarm with a break glass call point and attempted to fight the fire with a dry powder extinguisher. This was unsuccessful so he and all other members of staff left the building.

The brigade fought the fire in the ground floor through thick smoke and intense heat from the burning rubber polymers used in the manufacture of the occupier's product. They used 4 jets, an HP and 8 BA crewmen. Having extinguished this fire they realised that the fire had spread up the cavity between the inner and outer cladding to the second floor and roof. The total response to this fire was 12 pumps and 2 hydraulic platforms.

There was fire damage to 40 per cent of the ground floor and 70 per cent of the second floor. At first floor level there was only smoke and light heat damage mostly around the windows and other openings through the block work. There was also damage to the floor from the intense fire below.

The investigating officer believes that the temperatures of the fire exceeded the design specification of the wall linings. Its failure allowed the fire to penetrate into the wall cavity. This was fire-stopped with 12 mm Supalux at each floor level, but it is likely that the fire had caused sufficient distortion of the steelwork for the seal to be lost. The fire was then able to spread up the cavity and over the top of the block work into the roof and then the second floor.

The sandwich panels used for the external cladding were penetrated by the fire, and the fire did spread within some of them. However, there was no collapse of the panels and they were not considered to be a major route of fire spread to the second floor and roof.

3.19 Factory Building - Gateshead, Tyne and Wear

This building was a large single-storey structure approximately 10 m high and covered an area of 30 m x 50 m. The construction was portal steel frame which was externally clad with brick up to 4 m and corrugated steel sheet above. Internally it was lined with polyurethane sandwich board (PU with foil one side and paper on the other). The building was divided by a concrete block wall and then further divided by polyurethane and steel sandwich panels.

The building had been empty for 18 months and was being refurbished for use as an adhesive factory. The only persons on site at the time of the fire were four contractors. Two of these contractors were outside of the building close to the external wall. As they cut through the pipe work with an oxyacetylene torch approximately 3 litres of flammable liquid spilt out and ignited. This burnt against the external wall of the building. They attempted to fight the fire using a bosereel. When it was noticed that the fire had penetrated the wall of the building the brigade was called. Soon after this they were all forced to retreat by the intense heat and thick black smoke.

On arrival the brigade found approximately one quarter of the building involved in fire and smoke logging in the rest on the other side of the concrete block wall. The total resources involved in this incident were five pumps and one turntable ladder. Approximately half the building was destroyed.

The quantity of sandwich panels in this building was relatively small compared to that found in cold stores or food processing plant. However, there was rapid fire spread to involve half the building in approximately 12 minutes. This was via the sandwich insulating board cladding on the inside of the external walls rather than via the sandwich panels used for internal partitions.

3.20 Warehouse - Crewe

The building was a warehouse of approximately 100m x 100 m. It was a steel frame construction with external profile steel and concrete panel cladding on the walls and steel cladding on the roof. Internally the whole structure was lined with polyurethane and steel sandwich panels. The joins between the panels were sealed with tape. Although the building was still under construction the client and the builder had agreed that the client could store material in the building before it was finished. The client was a manufacturer of tissue paper products and the materials stored included rolls of tissue paper 1 m wide by over 1 m in diameter. Since the building was unfinished there were no doors within the building so there was no control on access and the fire was very well ventilated.
A fire was started within the rolls of tissue and developed rapidly. The staff attempted to extinguish it by compressing the rolls with the forks of a forklift truck. However, it spread to the walls and rapidly to the roof. The entire top half of the building was damaged by fire and the rest heavily soot marked. Other buildings, 50-60 m away, were damaged by radiated heat and the vast quantity of black smoke produced. This information was also supplied by telephone to FRS and a full report has been requested from the brigade.

3.21 Brick Kiln - West Midlands

This fire took place in a brick drying oven. The process follows the firing of the bricks in a kiln and prevents the bricks from cooling too rapidly. It is heated by air ducted from a gas burner at a temperature of 170°C. The oven was constructed of sandwich panels within a sheet steel structure. Originally these were steel and mineral wool sandwich panels but when some of the panels were damaged they were replaced with polyurethane foam cored panels. Plywood battens were used in the construction of the oven and held the sandwich panels in place. The brigade's opinion is that this was the material first ignited. Since the oven was running the surface of the sandwich panels was hot and very quickly became involved in the fire.

Since the quantity of panels was small the fire was not particularly difficult to fight, but the brigade report that it was difficult to establish the extent of the fire spread within the sandwich panels. A thermal imager and thermal trace remote thermometers were used to establish this, a technique they also used during a fire in a chicken processing plant (See para 3.6 above).

3.22 Recent incident in disused food processing plant - Dunstable

As this report was nearing completion a small fire involving sandwich panels in a disused food processing plant in Dunstable, Bedfordshire, was reported to FRS. A visit was made to the site.

All equipment had been stripped out, but the sandwich panels remained. A steel door, complete with its frame, had been removed from a polystyrene and steel sandwich panel internal partition exposing the edge of the core material. The panels from above the door had also been removed. Intruders had ignited the exposed material and then attempted to put it out with a hosereel. When they did not succeed they left the building.

The brigade was called from neighbouring sites when smoke and flame was seen above the roof of the building. On entering the area of the fire the firefighters found it smoke logged but the fire could be seen in a column from floor to roof. As they prepared to tackle the fire three panels collapsed onto the floor. The fire brigade were able to contain the fire to the already damaged areas.

The sandwich panel partition went the full height of the building to the roof. There was no sandwich panel ceiling in that area and there was a glass fibre roof light above the fire. These roof lights quickly burnt through venting much of the heat and smoke. The brigade believe that this enabled their firefighters to control the spread of the fire.

The opportunity was taken to inspect the rest of the building, including the cold storage area. The chance to view the damage done to the sandwich panels by forklift trucks, in temperatures above freezing, was most informative.

3.23 Recent incident in industrial building, Perivale, Middlesex

Also as this report was being completed FRS was informed of an incident in which an engineer using hot cutting equipment to repair a roller shutter accidentally ignited the expanded polystyrene insulation in the building panels. The fire spread upwards causing the aluminium exterior panel to melt. A very high rate of fire spread is reported.

3.24 Analysis of Incidents

As stated earlier, a total of 21 incidents have been considered. Of these 10 are reports supplied with the responses to the Home Office Questionnaire on sandwich panels, eight are the result of FRS telephone contact, and four are incidents that been the subject of Fire Research Station visits:

1. Although both cold store and food processing plants are generally perceived as being of high risk, only two incidents involved purely cold storage buildings, Pontefract and Crewe. In Pontefact, the building was nearing completion of its construction when it suffered an arson attack. This new building and an older one adjoining it were both a total loss. The items first ignited were reported by the fire brigade to have been stored building materials, including slabs of polystyrene. Buildings are generally susceptible to arson during construction, but the presence of plastic foamed insulation material on site could increase that particular risk of a major fire. At the time of the fire, 14.38 h on a Saturday there were no authorised persons on the site and no security measures. It may be assumed that had there been adequate security on site this fire would probably have been prevented.

The other cold store incident involved a 4-storey facility in Crewe. This was the only multi-storey use of sandwich panels found during this review. This fire started on the first floor within a sandwich panel partition. An electrical cable supplying a door motor overheated and ignited the polystyrene core material. Even though the source of ignition was relatively small and it is likely that the oxygen supply to the fire was limited in its early growth, it still spread to involve all four floors of the building.

There is also a report of a fire in a small cold store within a greenhouse. The firm grew strawberries and required temporary on-site cold storage of the product. The sandwich panels were used to form the cold store within the glass house and were probably more susceptible to an external attack by fire than they would be in a dedicated cold storage building.

2. On the basis of the information available, cold stores cannot therefore be regarded as a particularly high fire risk. However, four of the incidents in food processing plants involved electrical equipment that could also be used in a cold store.

3. Twelve of the incidents studied involved food processing plants. They all used sandwich panels for internal partitioning. In all cases except for one, a creamery, the internal sandwich panels were involved in the fire. The fire at the creamery started in a brick building outside the main structure. It spread to the external sandwich panel cladding the main building damaging approximately half of the exterior.

In all but one of these twelve incidents in food processing plants the cause was established as being a fire in a particular item of equipment. The odd one was a fire in a chicken processing factory where the brigade believe that it started in stored packaging material. They were unable to establish whether the ignition in the packaging was deliberate or accidental.

Six of the above twelve fires, ie 50 per cent, were caused by equipment used in a production process. In each case a different piece of equipment was responsible, ie a fryer, an oven, a defrosting machine, a freezer, a dryer, and smoke room equipment. Therefore it is not possible to pinpoint a particular type of machine as being a greater hazard than any other. However the fire in two of these machines, the fryer and the oven, and possibly in a boiler in another case, spread to the sandwich panels via a duct or a flue, which passed through the panels.

In two of the fires in food processing plants electrical wiring faults in the roof voids above the ceiling sandwich panels were reported as the cause of the fire. In both cases it was undetected until the fire or the smoke was seen below the ceiling. These electrical faults each resulted in the total loss of the factory.

Two other causes in food processing plants were reported. One was a fault in a portable air scrubber used to remove the smell of floor adhesive from a chiller, and the other was a conveyor belt run soon after hot working had been carried out on it.

It is noted that only five of these 12 incidents in food processing plants involved plant that was in production at the time. In all other cases , ie 7 incidents, the factory as a whole was not in production or the equipment involved was not in use, or some form of maintenance work or servicing was being carried out.

4. Fire brigades suspect that small fires are not uncommon in food processing plants and are routinely extinguished by staff. If staff are not present when a fire starts, or the fire is hidden or the cause is not routine, it is then more likely to develop and spread into the sandwich panels, with a possible loss of the factory.

5. Five further incidents were in factory buildings.

Two incidents, at Clwyd and Gateshead, involved buildings that did not contain sandwich panels but used insulation board in the external cladding of the building. Another in Shropshire only involved the use of external cladding sandwich panels.

The remaining two incidents reported to us were in a paper warehouse and a brick kiln. The brick kiln is interesting in that mineral wool sandwich panels had been used to line a drying oven. Damaged panels had been replaced with polyurethane panels. The fire spread through the polyurethane cores but not the mineral wool. It is not known if the choice of polyurethane as a replacement material was the result of ignorance or a need to cut costs. However it does highlight a need for care in the replacement of panels and an understanding of where they are to be used.

6. All the fires that involved sandwich panels produced large quantities of black smoke. In many cases firefighters needed to use breathing apparatus while working around the outside perimeter of the building. In one case eight spectators in a nearby water park were taken to hospital suffering from smoke inhalation. Even the incident in which the polystyrene sandwich panels were only involved in a smouldering fire produced large quantities of black smoke.

7. In eight incidents the fire brigade were unable to carry out firefighting within the building and in another three they were forced to retreat from the building. There were several occasions when a fire brigade thought they could send in a BA crew to extinguish a fire in a machine and then found that it had spread through and above the panels to involve the whole of the building requiring a rapid increase in response.

8. With one exception, in Crewe, fire in processing plants involving internal partitions constructed of sandwich panels resulted in the total loss of the building. Where they were connected to other buildings fire usually spread into those buildings often causing the loss of entire complex as in Pontefract.

9. Two firefighters died in Hereford, trapped by the collapse of panels, but they are the only fatalities reported. Other brigades also report panels collapsing as they retreated out of the building or fought the fire from the entrances. Injuries have been sustained , as in Hull, where firefighters have been exposed to escaping ammonia.

10. In all of the incidents except one a complete evacuation had been carried out by the time the brigade arrived. In the Hull fire, two members of the staff continued to fight the fire until they were told to leave by firefighters. The brigade believe that since they were close to an emergency exit they were unlikely to be trapped. However they were unaware that the sandwich panels above them were burning and there was a spreading fire in the roof void.

4. SITE VISITS TO SELECTED WORKING BUILDINGS

4.1 Introduction

The FRS team have visited six sites, which are believed to represent a reasonable cross-section of relevant properties. These are:

(i) A public cold store, with repacking area

(ii) A public cold store, with repacking area

(iii) A public cold store, vegetable processing and repacking area

(iv) A vegetable processing factory, including privately- owned cold store,

(v) A public cold store.

(vi) A public cold store

The first five of these visits were all kindly arranged for the FRS team by the Secretariat of the Cold Storage and Distribution Federation; the last visit was arranged by the West Midlands Fire Service. All of the hosts at the properties visited were very helpful and quite open in discussion.

In the public cold stores, space is rented by customers who own the goods stored. Other customer services may include freezing of freshly picked vegetables, cooking and freezing of vegetables, or repacking of frozen material. The privately owned site was one where various foods were processed, frozen and cold stored ready for distribution and sale. In most cases goods were stored in cardboard cartons or packets on wooden pallets in the cold stores; it is understood that high density polyethylene pallets have been considered but are regarded as too expensive an option at present. Wooden pallets are costed at £5 each while some are used as part of a chartered exchange system. The cold chambers are run at around -25°C with blast freezers down to -50°C (including wind chill factor).

It has not been possible to give an estimate of the fire loads in these buildings as not all the panels could be identified. However, substantial fire loads have been observed that, apart from the panels, include the wooden pallets and cardboard boxes containing goods, as well as the polymeric materials such as bags and polyethylene film sealing the palleted goods.

Although some record photographs were taken at some of the sites, it was agreed, at the request of the site managers and the CSDF, that these would not be included in any report since individual buildings might be identified. Consequently the FRS team was provided with a very open view of the fire safety issues facing these types of buildings.

4.2 Site 1

This public cold store, built in stages between the early 1970s up to 1982, provided three cold chambers of 8,500 pallet capacity and a central two-line packing hall plus a dry storage area outside this complex. There are more than 200 customers who rent anything from 5 to 2,500 pallets at any one time. Goods are loaded from an open air platform outside the two cold chambers. The cold chambers were steel frame and steel clad with internal insulation provided by 150mm polystyrene-cored sandwich panels walls and ceiling, the joints were taped. The walls were supported by a 150mm plinth on the floor providing a channel for the panels. The suspended ceiling created a large surface area within the roof space which the FRS team was able to examine. The packing hall was brick built with plaster and tile lining recently overboarded with a GRP laminate at a major customer's request to improve the food safe performance. While on site frozen rice was seen being mixed with spices and repacked in bags for a large retail chain. This process took approximately 40 min and involved the material losing about 8°C while out of the cold store, which is reported to be the sort of tolerance allowed by the food industry on health grounds. Packaging materials were stored well away from the process areas in an adjoining building and were taken in as needed for each shift to prevent build up of combustibles.

The 85 staff work a two-shift five-day system, with casual staff buffering the workload. At the time of year of the FRS inspection (March) cold stores expect to be 65 per cent full but were actually almost at full capacity. In the packing hall there was a fire alarm, fire extinguishers, hoses and an emergency exit; fire drills are every three months and we were shown records which indicated an average evacuation of the whole complex of under two minutes. Fire training is part of the induction of new staff and is carried out most weeks. In the cold chambers there were 'locked in' alarms and fire exits, all of which were, however, observed to be blocked by goods on pallets.

The FRS team was shown round by the Operations Manager and the Chief Engineer who were very knowledgable about their buildings and the processes within them. There had been a serious fire in the 70s under previous ownership where one chamber had been badly damaged, but none under the present owners. There is one security man for the quiet hours with a mobile 'phone. The site is lit externally, but there are no cameras.

4.3 Site 2

This was a small public cold store comprising three stand-alone buildings on a 4 acre site with twelve staff operating a single shift system. Numbers 1 and 2 coldstores were built in 1962 with a thousand pallet capacity each; Number 3 was built in 1979 with a 3,500 pallet capacity. The present owner took over the property in 1989 and has slowly been improving the existing facilities with much investment in the fabric of the buildings, especially Number 3 coldstore where the piling was ineffective and the building had been sinking. All three have double brick skin exteriors with steel and timber roof structures. Numbers 1 and 2 were completed in 1963/4 by building a thermalite block inner wall leaving a cavity between it and the outer brick skin. 100 mm of expanded polystyrene was fitted onto wood battens on the thermalite and then chipboard on the inner face. The ceilings consist of timber beams with chipboard supporting 200 mm of extruded polystyrene with cold bitumen brushed on to seal it. This had recently been redone and the FRS team was able to examine its condition in Number 1 coldstore, where the roof timbers were very dry and clean. Number 3 coldstore had been assembled by a local builder in 1979. In this building there was an inner wall of breeze block with battens supporting extruded polystyrene and then a galvanised sheet to complete the insulated layer. The metal sheets were held in place with long screws that went through both the breeze block and the paper vapour seal in the cavity. The ceiling consisted of two layers of extruded polystyrene with builder's paper and bitumen; the joints were taped. Again it was possible to see the repainted steel and re-bitumenised layer in the roof void completed over the last three months. All electric cables were in trunking and air conditions were being closely monitored. The owner was aware of the predilection of this type of ceiling construction to collapse due to build up of ice, but he has not had that problem which he ascribes to the use of timber, rather than steel, in the roof construction; the wood absorbs the additional moisture which freezes and then drains off. He had a system for collecting such water which appeared very effective.

The loading bays had been covered in to prevent extremes of temperature causing problems just inside the doors of the cold stores. There was very little frost build up in these stores. As much of the material stored was offal awaiting conversion into pet food, security was minimal and consisted of locking the buildings and the access gates. There are dummy cameras which sometimes have film in. There are extinguishers and hoses, break glass call points. The plant room had been identified as a high risk area and alarms and venting had been fitted. Because there is such a small staff, and they are all so involved with the business, fire drills are informal and there is continuous exchange of information as to the whereabouts of personnel. Fire exits were all clear of obstructions in the three buildings.

4.4 Site 3

The site was owned by an international group and on a much larger scale than the earlier two. It had been at this location since the early 1970s and had been developed and extended up to the late 1980s. This public cold store consisted of sixteen cold chambers, two packing halls and two separate factory buildings, one for the cooking and freezing of vegetables, the other for the frying and freezing of chips. The cold chambers are arranged ten to one side of the packing hall, five to the other and one large chamber (Number 20) quite apart from the rest. This reflects the development on the site and an ability to continue trading if part of the site of the site is out of action. Goods were stored on pallets as before but mobile racking is used extensively.

The majority of the buildings were steel frame and steel clad with a variety of insulants used. Cold chambers 1-10 had wall linings of cork/bitumen/ fibreglass with steel faced internal sheeting; the ceilings of 1-8 were polyurethane foam core panels with steel facings laminated to the core while in 9 and 10 fibreglass in timber boxes with metal facings were used. Chambers 5 and 6 were linked by the simple expedient of cutting through the walls which exposed the core and when the FRS team was on site the access was blocked by pallets of goods. The walls and partitions of chambers 11-15 and 20 were polyurethane foam core with aluminium faces bonded to the core with the roof of high density polystyrene on metal decking with felted vapour check weathering surface. One packing hall had cold storage at first floor level with walls and ceiling of polyurethane core bonded to steel faces; the other packing hall had walls and ceilings of expanded polystyrene core with laminated steel faces. The first factory used for preparing frozen rice from raw grain during the visit had ceiling of expanded polystyrene core panels with laminated steel faces, the walls were finished with resin and fibreglass resin, some partition walls as the ceiling. The blast freezers had walls and roof of polyurethane foam bonded to steel faces. In the second factory chips were being made in a brick and steel building with blast freezers as in the first factory. The loading dock to chambers 1-10 was open to air with ceiling of expanded polystyrene core with laminated steel facings. The enclosed loading dock to chambers 11-15 again used polystyrene cored steel panels for walls and ceiling.

This fenced site was very secure with cameras on all the buildings and fences, and detailed knowledge of the whereabouts of staff and lorry drivers (This was a major improvement over past practice from when there were stories of frozen joints being lobbed over fences.). Picking of stored material and delivery to the loading bays and to the container lorries was under computer control. Lorry drivers can use a key pad to find out where to go. The cab was driven away during loading to reduce the fire risk. There have been very occasional fires in the lorries; anecdotally the freezer units have been slightly more of a problem.

Fire precautions in the buildings reflected the usual approach including fire extinguishers, hoses and break glass call points. There are regular fire drills but these are mostly area based with only one total evacuation drill each year. The 500 staff work three shifts for five days, taking on extra staff at pea and bean picking time (when from plant to frozen pea or bean takes 150 min). This is an intensive six week period when the facility is used twenty-four hours a day for seven days a week.

4.5 Site 4

This private sector plant is dedicated to the production and cold storage of both fish and vegetable products. There are two very large cold stores and two factories, one for fish and one for vegetables which date back 30 years.

The fish process area is contained within masonry block walls with corrugated asbestos sheeting roofs supported on steel trusses and steel purlins. A suspended ceiling incorporating mineral wool is hung below the trusses. In the newer areas of the factory and in some extensions expanded polystyrene cored sandwich panels have been used. There are three deep fat fryers in this area with service and switch gear on a level above. The main cabling loom from this switch room could be affected by a fire in one of the deep fat fryers, with major disruption to business. Means of fire protecting the loom were being considered. Different ways of forming fire compartments around each fryer were also being examined but there was an awareness that this would limit means of escape. The roof voids above the preparation areas had hanging cavity barriers of mineral wool in chicken wire curtains, but these were much penetrated by services and walkways. If a fire were to reach the switch room it could also penetrate this roof void which is effectively undivided.

The two adjacent cold stores have walls and roofs incorporating either expanded polystyrene or polyurethane cored sandwich panels. There was exposed polyurethane around the doorway to one of the cold stores, evidently due to impact with fork-lifts, and exposed polyurethane where the skin of panels had been torn, probably by pallets moved too close. Roof panels have been reinforced with large metal plates or washers and bolts which penetrate the panel to provide support. This is remedial treatment to prevent slumping and collapse of the panels due to ice build up between the two sheets of steel. Roof panels in one cold store have recently been replaced at an estimated cost of ,300k with a further cost of ,500k due to downtime and renting other storage facilities. The roof void above the new ceiling was ventilated via tiles at the ridge only without gable or eaves ventilating grilles. There was a high build up of ice in the roof void over the older cold store, generally at joints between the panels and at connections where there were light fittings or where steel connections supported the roof structure. The plant manager was very concerned about the effect this ice loading was having on the primary structure. The two cold stores had been separated in the roof void by a 100 mm thick block work wall . During the recent renovation this blockwork had collapsed and not been replaced although a fire door linking the two voids was still in place and was used for access.

Behind the cold stores was a flat roofed area for services most of which appeared to have been accommodated on an ad hoc basis.

The loading bays were open to air so goods are taken directly from the cold store to the lorries by fork lift trucks. The charging points for these trucks were along the loading bays. Pallets were stacked against the fabric of the building but were not seen elsewhere.

There were high standards of cleanliness in the preparation areas but these standards did not continue into service area, cold stores loading bays etc which were grubby and disorganised. (Note; this contrasts with the public cold stores where all areas appear well maintained and serviced . This may reflect the fact that public cold stores and food process areas are regularly visited by customers who dictate the standards, rather than the owner-occupier in this case). It was not possible to carry out a formal fire load audit. However, the factory contained substantial quantities of cooking oil, in use, stored for later use, and waste for disposal or animal feed, pallets and packaging, as well as product. There was large amounts of cabling, mainly above the ceiling. The cold stores contained pallets, product and packaging.

4.6 Site 5

This public cold store consisted of one large cold area, a loading bay and other service areas housing pumps, electrical equipment etc. The cold store was one undivided area where the frozen foods were stored in large boxes on wooden pallets at about -25°c; there was a central walkway with aisles either side to gain access to the stored goods with some of the goods on a moveable racking system or on high level mezzanine decks. The store was constructed of sandwich panels which were 10 m in length and contained expanded polyurethane; they were joined together in a form of tongue and groove method, locking with a key; the joint was then filled with mastic. The external walls consisted of metal cladding, insulation, metal cladding, an air gap (the width of the steel beam which was part of the structure), a fire wall (either block work or fire resistant panelling) and finally external cladding (fascia). The goods were generally taken from the cold store on a forklift truck to the enclosed loading bay which was adjacent. This area was insulated with the same panels and also monitored for temperature fluctuations. The goods then went directly onto the container/lorry for shipment. The loading bay was a dry area which was constructed of breeze block work. There were 20 staff working on this site. Only the supervisors were trained in fire safety procedures. There was no automatic fire detection system but there were some ionisation smoke detectors and manual call points.

The use of substantial quantities of chemicals is necessary in a cold storage depot and this one used ammonia as the refrigerant and glycol for underground floor heating, using waste heat from the refrigeration plant. There are six large fans in this cold store which circulate the air around the area and are located at high level on the side walls.

The cold storage area is in good condition with little or no damage to the sandwich panels. However there are many holes in the ceiling panels for services to pass through, in particular lighting. The roof void is free of any obstructions and a walkway had been built above the sandwich panel ceiling; however it is necessary to stand on the panels when changing a light bulb and carrying out similar services. The panels are said to be able to support the weight of two people. There was no frost evident in the roof void which would indicate a good seal on the panels.

The procedure used to pass service wires through the sandwich panels was explained as follows: an on site electrician carefully cuts a hole in the panel (i.e. there is no hot working); the twisted strand wiring (encased in a butyl material; this prevents fracturing) is passed through the hole and then mastic is used to fill up the exposed hole leading to the internal insulation of the sandwich panels. Any damage which does occur to the exterior of the panels is patched using metal cladding and then pop riveted into place.

4.7 Site 6

This public cold store was custom built seven years ago in 1989 of steel frame construction with profile steel sheet externally and with expanded polystyrene filled sandwich panels bounding the cold rooms. The site is shared by two tenants and is now used twenty-four hours a day. As the store was built on a sloping site part of the store had been raised about 300 mm. There was some accumulation of debris beneath the floor.

The front of the building is offices and loading bay, behind that, there is large cold store, some smaller chill rooms and blast freezers. A battery charging room had been built as an extension to the loading bay. The store appeared to be well maintained and managed and our guide was helpful and enthusiastic.

The cold rooms were surrounded by void formed between them and the steel exterior. The void contained services with access for maintenance. 'Workshops' had been in this void until it was realised that hot working so close to the sandwich panels was unwise and the workshops were moved to another area well away from insulated panels.

Within the main cold room goods were kept on middle height mobile racks, each section capable of holding 300 tonnes. The racks were moved by electric motors. Other cold rooms, had been adapted to run at slightly higher temperatures with storage was on fixed racks - this particular store specialised in chocolate goods. However, the client was planning to build a chocolate store elsewhere so this one would adapt the dedicated chocolate rooms to general cold store rooms.

Joints between panels were usually sealed with mastic- type sealant (some joints were incompletely sealed). Some damage appeared to have been repaired by riveting a piece of steel plate onto panels.

There was little obvious damage to the insulated panels, except in a recently built partition wall between a chill room and the main cold store, and between the battery charging room and loading bay. The manager told us that there was a rolling maintenance and repair programme to cope with small-scale damage mostly from fork-lift trucks. Doorways were very vulnerable and both users were investing in good quality stainless steel finishes which are harder to damage.

4.8 Consultation with industry

The relevant sectors of industry have been consulted as widely as possible during this study. The opportunity was taken to attend two relevant conferences; the CSDF Ancillary Members Conference at Grantham in February 1996[22] and the Loss Prevention Council Conference on Fire Safety in the Food Processing Industry in London in March 1996[25]. These both proved most helpful to the study. In addition, face to face meetings have been held with BRUFMA representatives, CSDF representatives, Rockwool and Kingspan, as well as the most helpful discussions at the various sites visited. BRUFMA kindly arranged a visit for the FRS team to see the Kingspan production factory at Holywell in March.

A short presentation on the current study was given to the Annual Conference of the International Association of Cold Storage Contractors (IACSC) UK Division at Peterborough in July 1996[25a].

4.9 Comments from and on the industry

1. One of the owners pointed out that the 1970s saw the rise of cold stores followed in the 1980s by increasing food process and distribution centres; in the 1990s the influence of Brussels legislation has been felt. The FRS team saw no evidence of expansion on existing sites although new locations are being developed, for example the huge hub distribution centre opening in the West Midlands.

2. Any cold store must control the moisture that can be pulled into the building because of the temperature gradient or the vapour pressure gradient. One approach has been to use timber where moisture goes onto the timber and then defrosts and drains off in a 4, 6 or 8 h cycle. The latest design idea is to not seal the inside joints but allow moisture to freeze, defrost and drain off in a controlled way and so prolong the life of the cold store.

3. One owner discussed the importance of vapour seals and panel spans and the need for food safe surfaces with modern day sandwich panels. He also pointed out that there can be problems with floors as the permafrost, from the constant low temperature of the cold store, must not go too deep. Solutions to this problem varied and included recirculating glycol used on one site or heated electric mats on another. Another site operator informed FRS that 40% of the building cost is in the provision of the heated floors for the cold stores.

4. There was clear evidence of mechanical damage to the insulated panels in the cold stores caused by the fork lifts vehicles, either directly or by pallets or loads. In the event of fire in the very dry conditions of a cold store, heating of the exposed polymer would result in rapid fire spread. Instances of poor housekeeping were also noted, which can lead to, or aid, spread of fire.

5. Most cabling the FRS team saw was either in conduit or heavy duty insulation. Not all services were fire stopped where they penetrated panels. FRS was informed that the use of butyl multistrand cable is the best choice as it does not weaken under the thermal gradient.

6. It was clear from the discussions with the security chief on Site 3 that food safe conditions were paramount for them, with fire safety being of far less importance, if considered at all. Building layout on many of the sites generally meant that a fire in one building was unlikely to spread to others. However, on site 4 there were rows

of houses adjacent to the process buildings, cold store buildings and ammonia tanks on both sides. In the event of fire there are obvious implications for those residents who may need to be evacuated.

7. There were varying approaches to staff training - in one case only the supervisors received fire training, while in another there were regular evacuation exercises and all new staff received specific fire safety training.

8. In some buildings fire exits were blocked by goods on pallets. This compromised the means of escape, which in turn may already be compromised by the compartmentation creating very large spaces for staff/firefighters to move through. In addition, a fire might be spreading through the combustible core of the panels around and above the means of escape.

9. In such cold conditions as are found in the cold stores , the effectiveness of detectors at high level, and extinguishers on burning material stored up to 10 m in height, has been questioned. Dry sprinkler systems might offer a solution but problems with lagging the piping for such systems have been noted.

10. In only one case was plant observed in the roof spaces; most building owners were keen to separate their plant from the actual stores.

11. Risk assessment within these buildings has been addressed by the Loss Prevention Council[13] where normal risk is defined as covering most food process areas and high risk is exemplified by deep fat frying areas, concentration of packaging materials, storage of finished goods and plant areas. It is interesting to note that the Northern Foods speaker[26] at the LPC Conference[25] had believed that he was working in a low risk area until a demolition worker, clearing panels in one area of a factory, used a blow torch to cut them and caused a fire which destroyed the whole building .

12. Panels are connected to each other by various means. The older panels have a locking strip that fits in a groove in each panel. More modern designs involve a locking hook mechanism. It is far from clear that any of these systems would be able to resist a fire.

13. Panels are replaced from time to time as buildings are upgraded. As a result there appears to be a thriving "second-hand" market for "used" panels, but the applications for such panels are not clear.

5. DISCUSSION

DOE has recently[27] provided convenient categories for the areas of concern with fire safety in the food processing industry; occupant safety, firefighter safety, property safety and environmental safety. There appear to be little evidence to suggest a need for special concerns about occupant safety; in all cases investigated here the occupants had left the building safely before the fire had developed sufficiently to put them at risk. The low risk to occupants is borne out by the HO fire statistics[17]. However, firefighter safety has become of concern following the Hereford incident. As the incidents above show, many brigades have identified unexpectedly rapid fire spread leading to collapse within these buildings as an increase in risk to firefighter safety.

The cold store industry takes a particular view of the losses it risks since FRS have been informed that 40% of the cost of a cold store building is in the floor. It follows that for this industry the damage to the contents may be of greater importance than the loss of the building structure.

The insurance world is concerned that direct losses account for half the claims in the food process industry, with loss of business comprising the other half[28]. A similar distribution of costs might be expected in areas such as the pharmaceutical industry and where the insurance industry response might be expected to be similar. The same constructional techniques are also used in retail premises and hospitals, but there do not appear to be the same problems with sandwich panels.

Environmental pollutants have been produced by some of the fires surveyed, for example at Hereford and Pontefract. Concerns may well be raised in this context by those concerned about food production if combustion products could enter the food chain.

Very few of the fires surveyed have been deliberately caused. This may reflects on the commitment of the staff in the food process and cold store areas to safe working practices, as well as to food hygiene. This attitude may change should the current BSE scare result in the collapse of part of the meat industry, and no doubt insurers will not be surprised if there are some serious fires in abattoirs, meat processing factories or meat stores in the near future.

In discussion with various parties it has become evident that there is confusion regarding the different types of sandwich panels and composite panels, and the expected nature of the fillings. It appears to be the case that the polymer content of many sandwich panels was not recognised or appreciated until the Hereford fire and the publicity that was generated about the behaviour of panels in fire.

The sandwich panel manufacturers are addressing the fire problem in two ways; many of the panel manufacturers who use polyurethane foam are developing products that will pass fire resistance tests and so provide a measurable response to fire[29]. Those who use polystyrene are taking the approach of providing guidance to users[5] , pointing out the implications for building design and use of their product.

The panel manufactures who use mineral wool are confident that the non-combustibility of their product makes it an alternative to the polymer fillings. However, the food industry is clear that it must avoid any direct contamination from the fibres associated with the product, or any risks of microbiological infestation, which is currently seen as problem with fibrous fillings. It is also said of mineral wool that should the panel admit water then the wool, being very absorbent, will increase the weight of the panel beyond the limits of the supporting structure.

Manufacturers of intumescent materials are providing materials that may further improve the fire resistant properties of the panels in use thus allowing upgrading of existing premises. It appears that the industry is either consolidating what it already owns or is seeking to expand only in new geographical areas.

The sandwich panel industry is highly competitive, both between the different product types and between individual producers of each particular type. It would appear to be advantageous if a single unified approach was adopted by the industry to improve the fire performance and fire safety of sandwich panels. However, FRS is aware that there some overtures between the different sectors are being made, but these are not well publicised.

Mention has been made elsewhere here to a review for DoE of the HO fire statistics for fires in meat production and processing industries, cold stores and refrigeration plant[17]. This study provides a useful addition to the present research but is not summarised here. However it may be noted that in the period 1990 to 1993 there were about 60 non-fatal casualties in these fires of which about half were fire service personnel. The only fatal casualties were the two fire officers referred to elsewhere in a meat processing factory fire.

FRS has noted that the fuel loads in these buildings are large, consisting of cellulosics; such as wooden pallets and cardboard boxes, and polymerics; such as bags and film wraps round the pallet, as well as the actual food, which, being very cold and dry, is readily flammable. All these materials should be easily extinguished using water. However, the fuel load presented by the polymer cores of the sandwich panels is of a different character because a fire within the panels is unseen, protected from water, and with long reaches of interconnected panels which allow the fire to spread.

There is an additional risk where the polymer cores are exposed as a result of penetrations for fixtures and fittings, such as lighting, ducts and flues, or by damage from fork-lifts etc. There is an obvious need for good housekeeping and the application of effective fire safety management procedures. This issue is being addressed by parts of the industry[5].

From the incidents studied there is clearly a problem for fire brigades wishing to fight these fires from inside the buildings, in particular, there is the hazard from collapsing panels, as in Hereford and Hull, but also the risks from escaping ammonia and other refrigerants. It may be noted that Bucks Fire Brigade have taken the decision not to enter these buildings if there is no life safety need.

Cold stores do not clearly present a fire safety problem. But hot working of any kind within any type of building is shown to entail risks. This is the case both during normal production and also during down-times, such as for repairs and maintenance.

Many of the incidents studied here have involved machinery of some kind, with a few electrical in nature. The potential for such fires was highlighted on Site 4 where the main cables all passed over the process (high risk) areas above ceilings and in roof voids.

All evacuations of the occupants in the cases studied were successful, though not entirely without risk.

It would appear that a method of identifying the type of sandwich core would be useful to owners, operators, and the fire service. However any proposals to develop such a scheme is likely to be lost in the context of European labelling requirements. One suggestion has been to place a label near to the control panel since the fire brigade will always look in that location.

Manufacturers who kindly agreed to supply samples of used materials for this project found difficulty in doing so since it was discovered that there is a thriving "second hand" market to supply salvage yards. It is not clear to what end uses such second hand panels might be put, possibly agricultural use, but it is evident that second hand panels might be difficult to control or regulate.

6. SMALL-SCALE EXPERIMENTS

6.1 Introduction

In the third phase of this current project FRS has explored the fire behaviour of the range of panels by a series of ad-hoc laboratory studies. These studies were selected on the basis of the findings above and comprised cone-calorimeter tests and tests on 1m to 2m small panels including a large calorimeter test . It was intended that these tests should examine all of the different types of sandwich panel currently in use and would include steel skin panels with cores of expanded polystyrene, extruded polystyrene, polyurethane, fire-retarded polyurethane and mineral wool. The other types of panel would not be included in this initial review. However, it has proved impossible to date to obtain all of the required types of panel since some are no longer produced and the only source would be as scrap from refurbished buildings. As mentioned above, a "second-hand" market for panels has also limited their availability. Although efforts continue to obtain other panels, the tests reported here involved only polystyrene, fire-retarded polyurethane and mineral wool. However, this selection appears to cover the range of expected fire performance and to have provided the required indicators of fire behaviour.

6.2 Cone calorimeter tests

The objective of this work was to carry out a series of non-standard cone calorimeter tests to determine the ignitability and rate of heat release on 100 mm square samples. The tests were guided but not constrained by ISO 5660 since the results are to assist in the objectives of this initial review and are not to be used for formal ranking or certification. Samples tested involved;

(i) metal skin and core, metal skin exposed,

(ii) metal skin and core, core exposed.

As mentioned above, the three types of sandwich panel core assessed were;

A. Expanded polystyrene,

B. FR polyurethane,

C. Mineral fibre.

In addition a sample of PVC coated panel with polystyrene backing was available from an FRS fire investigation and was included as sample D. Samples were cut to fit the sample holder of the Cone Calorimeter. Initially, only a single sample was to be tested at each irradiance level with further tests depending upon the outcome.

It needs to be noted that the regime for these tests allows for heat to reach the core around the edges of the steel, and similarly for combustion products to be emitted. The tests therefore may be seen as representing a worst case for the exposure to radiant heat and an ignition source. In addition, the samples are all exposed in the horizontal, which, as will be discussed later, will permit any liquified combustible material to collect and burn.

Sample C, the mineral wool core, did not ignite in any of the tests and although some light smoke was emitted on initial exposure, no results were collected. As might be expected, sample D, PVC with polystyrene, produced the greatest amount of heat and smoke, with less from sample B, FR Polyurethane, and from sample A, Polystyrene. Sample A ignited more rapidly than B when the metal skin was exposed, but sample B ignited more rapidly than A when the core was exposed.

6.3 Ad-hoc small-scale tests

The purpose of these tests was to provide some indications of the way sandwich panels may be ignited and how they burn, so as to provide some practical experience that would assist in the assessment of the case histories and to provide some guidance in the development of proposals for a more structured experimental research programme, should that be appropriate. It was not intended to duplicate the work elsewhere to develop a formal method of test for such panels, but it was hoped that the experiments would assist in that activity.

A programme of tests was drafted that was intended to comprise the following;

(i) Indicative ignition tests on supported 1m x 1m samples of the panels. Ignition sources used would include a match, a blow torch (for a defined short period), a blow torch (for a defined long period),and a liquid fuel (alcohol pool).
Samples would be assessed in the vertical and the horizontal. No measurements would be taken but a video record would be made. Observations would be made of ease of ignition, sustained ignition, speed of spread, delamination and smoke production.

(ii) Scaled up tests to assess the response of selected types of panel to thermal radiation using quantified heat fluxes from a radiant source. Tests would be carried out on vertical whole panels, eg 2m x 2m, but with a sealed vertical joint and with penetrated fittings, eg a light fitting. This test would simulate exposure of a wall from a nearby fire but with no direct flame impingement.

(iii) Similarly, scaled up tests to assess the response of selected types of panel to direct flame impingement using quantified heat fluxes from a gas burner. Tests would be carried out on horizontal whole panels, eg 2m x 2m, but with a sealed joint and with penetrated fittings, eg a light fitting. This test would simulate exposure of a ceiling from a nearby fire with direct flame impingement.

(iv) Full scale tests on single 3m high, 4m wide panels, using the FRS large calorimeter. The panel types would be selected on the basis of the earlier tests. Each panel would consist of two elements, each 2m wide, jointed, and equipped with typical penetrative fixtures. If appropriate, the panel might be "damaged" to expose the core. Thermocouples on the skin and an infra-red camera would be used to track fire spread within panels. Of particular interest would be the effect of different joints and penetrations of the panels. The fire source would be a gas burner to ensure sustained ignition. The panel would be supported at an angle by one skin, to provide some self-loading and so that any delamination will be evident. Routine calorimeter measurements would be carried out, including rate of heat release and smoke and gas production.

This test would be intended to assess the behaviour of the panels once a fire is well established in the core, in particular, the speed of spread within the core.

As mentioned above, it was not possible to obtain samples of all of the different types of panel within the period of the project, although a number of organisations were actively seeking, and continue to seek, scrap panels from refurbished buildings. While the panels that were obtained comprised only four different types and of limited dimensions, FRS was given a substantial quantity of three types of panel. This meant that the proposed test programme above would have to be modified to take account of the actual material available. Although it was not possible to fully implement the programme the primary objectives were achieved.

Test 1 - Expanded Polystyrene, vertical.

The panel tested was 100 mm thick, 0.85 m wide and 1 m high, held loosely in a frame. A burning taper was held to the polystyrene which melted away without ignition. Similarly, no ignition could be sustained using a blow torch despite efforts to "chase" the polystyrene. Ignition was eventually achieved using a 30 kW gas "T" burner for about 5 minutes. The fire progressed through the panel with all the polystyrene consumed. The test was carried out with thermal imaging and video recording but no other instruments.

Test 2 - Expanded Polystyrene, horizontal.

This panel was 100 mm thick, and 2.75 m by 1.2 m. It was supported on a trestle approximately 0.3 m from each end. Ignition was achieved using the "T" burner and the fire progressed steadily through the panel. Large quantities of yellow smoke was emitted once the fire was well developed. Once sufficient polystyrene had been consumed the panel delaminated and fell from the tressle, 30 m 45 s from ignition. The test was carried out with thermal imaging and video recording but no other instruments.

Test 3 - Fire-retarded polyurethane, vertical.

This panel was 100 mm thick, 1.2 m wide and 1 m high. The polyurethane would not ignite with either taper or blowlamp but was ignited with the "T" burner. The fire burned slowly and spread a little way into the panel before dying out. About 200 mm by 200 mm of material was consumed. The test was carried out with thermal imaging and video recording but no other instruments.

Test 4 - Mineral wool, vertical.

The mineral wool panel was 100 mm thick by 2m by 0.6 m. It was not possible to ignite this core either with a taper nor with the "T" burner. Following about 3 minutes exposure the wool was sooty but beneath the soot was undamaged material. Photographs taken of this test are presented in Annex 2.

Test 5a - Polystyrene, jointed vertical panels.

This test was carried out in the FRS furniture calorimeter and videoed. The test piece comprised two panels each 100 mm thick, 0.57 m wide and 2m high. They were jointed using a bolted 40 mm steel joint with wood spacers.

The "T" burner was put on for 30 seconds, then withdrawn for 15 secs. It was replaced for a further 15 secs before being withdrawn fully. The polystyrene burned with diminishing flames and was effectively out after 3 minutes. About 2 thirds of the polystyrene in the first panel had been consumed and a peak rate of heat release of about 70 kW was recorded.

Test 5b - Polystyrene, jointed vertical panels.

This test, also in the calorimeter and with video, was carried out on the remaining portion from test 5a. For this test the "T" burner was left on for the whole test. The sample burned continuously with the first panel collapsing after about 9 minutes. The joint held the two panels together but the fire had effectively consumed all of the fuel after 10 minutes a peak rate of heat release of about 0.7 MW was recorded.

Test 6 - PVC faced polystyrene, vertical.

This sample was about 1 m by 1 m. The "T" burner was kept on and the panel burned continuously and collapsed after about 3 minutes due to softening of the skin. Some polystyrene remained and the panel had not delaminated. The test was videoed but there was no other instruments.

Test 7 - Polystyrene, jointed vertical panel.

This test was carried out with thermal imaging and video recording. The test element comprised two panels each 100 mm thick, 0.6 m wide and 2.75 m high. They were jointed with a simple "tongue and groove" push-fit joint. The ignition source was a small tray of meths. The fire quickly spread up the first panel and smoke was emitted from the joint after 2 m 37 s followed by flames after 2 m 45 s. The first panel delaminated and fell after 3 m 25 s. The second panel remained upright until about 5 m from ignition and the fire was extinguished after 11 min.

6.4 Discussion

These tests have achieved their objectives in providing useful background measurements and experience that will inform any future activity;

(i) None of the panels or the panel cores can be ignited readily with either a taper or a blowlamp. The polystyrene melts away from the flame, the other types of core are resistant to ignition.

(ii) Under more intense heating the polystyrene panels may sustain a fire depending on the geometry. If the molten polystyrene is able to flow away from the heat then the fire will diminish and go out. If the polystyrene is contained, for example, by the skin of the panel, then the fire may sustain itself.

(iii) The fire-retardant treatment for polyurethane (for the samples tested) appears effective. Mineral wool is clearly noncombustible.

(iv) Different jointing systems allow delamination to occur in different ways. Simple "push fit" joints allow ready delamination whereas bolted joints may provide some structural stability.

(v) Combustible cores will ignite despite the protection of the metal skin where the level of radiant heating is sufficiently high. Clearly exposed core, through damage or penetrations, will speed this process.

(vi) Thermal imaging can be used to identify the spread of fire within a panel. However paint charring follows the same pattern. Thermal imaging could be used in smoky conditions where the condition of the paint is not visible.

(vii) Fire can spread vertically through a polystyrene panel at around 1.5 cm/sec. Spread through horizontal panels may be slower, but speed of spread will depend upon the external heat source.

A number of issues have not been addressed in the current study but which have been high-lighted by the observations. These include questions regarding the effectiveness of sprinkler systems where the water will be deflected by the panel skin, and whether or not fire-retarded cores or incombustible cored panels might still delaminate under heating conditions that might affect the skin/core bonding.

Unused panels have been retained by FRS in case further testing is required.

7. CONCLUSIONS

7.1 Fire risk

(i) The findings of this study support those from statistics; that the risks associated with sandwich panels are primarily in fire fighting. While there may be circumstances in which members of the public or workers in a building are put at risk directly from a burning sandwich panel, the evidence here is that, if panels are the item first ignited, development will be fairly slow and contained and that panels will only contribute to an already large and dangerous fire.

(ii) For fire fighting there are evident risks. The fuel in the panels will contribute to the fire development, and the fire can spread quickly and unseen, both up and over fire fighters. They may also shield a growing fire above them which may be revealed suddenly when the panels delaminate and collapse.

(iii) Processing plants are a far higher risk than cold stores. Fires in food processing plants with internal sandwich panel partitions usually result in a total loss of the building.

(iv) Causes of fire include hot working and electrical. There are a small number of deliberate fires in the cases studied. There appear to be particular risks associated with maintenance.

(v) The use of sandwich panels is not restricted to the food industry and it needs to be recognised that fires with rapid hidden spread may also occur in other occupancies such as retail and health care, since the lightweight panels are more widely employed in these buildings.

7.2 Fire development

(i) Different types of sandwich panel burn in different ways. Mineral wool panels are non-combustible, and developments in the formulations of some types of polymeric cores will limit fire growth. However, there are many existing buildings that contain the older types of product.

(ii) Fires may spread within and behind panels (in the voids and cavities created by the panel structures).

(iii) Joint constructions present a weakness and may permit ready delamination, depending on the type.

(iv) The fires in a wide range of electrical and food processing equipment can spread to involve sandwich panels. Travelling ovens have been mentioned as having a high fire incidence by some fire investigators. Such equipment should never be used in conjunction with combustible insulated panels.

(v) Fixing of ceiling panels may only be by plate and bolt through the upper face. Where this is the case it is possible for the lower face to delaminate early on in a fire in the contents underneath.

(vi) Fires in roof spaces above panels were often undetected until flame or smoke spread beneath them. Rapid fire spread through unstopped roof voids has been the major route of fire spread through these buildings. The possibility of detectors and compartmentation in these spaces should be considered. Fixed venting needs to be explored but may remain an unviable option in the food sector. However, the use of sandwich panels is not restricted to the food industry and it is in other occupancies such as retail and health care, that built-in venting from the roof may have a role.

(vii) It has not been possible to establish how effective sprinkler systems might be on a fire contained within a sandwich panel.

(viii) In some buildings the ceiling panels, which have some load bearing capacity, have been used to support equipment. However, under fire conditions, the panels can loose strength and the presence of the load will cause ready collapse.

7.3 Operational issues

(i) Fire fighters need to be aware of the unusual fire behaviour of sandwich panels, in particular the risk of sudden delamination, which is both dangerous in itself, since large thin metal sheets may fall from a considerable height, but also from the fire spread that will occur.

(ii) Since fires may spread within and behind panels (in the voids and cavities created by the panel structures) the extent of the fire may not be apparent either to occupants or to fire officers.

(iii) Large quantities of black smoke are produced, making working difficult for firefighters outside the building as well as inside. In addition, there may be ammonia released from damaged refrigeration plant. There are a number of pollution risks from fires involving sandwich panels.

(iv) The use of thermal-imaging equipment should provide a useful tool to assist fire brigade operations, particularly in smoke where discolouration of the panel's paint cannot be seen.

(v) There is some difficulty in identifying the different types of panel once they are in place and the core hidden. It would be useful to the fire service, and to building owners, if there were some means of identifying the different types of panel once they were in place.

7.4 Management issues

(i) There is a need for good fire safety management and housekeeping in these buildings. FRS staff have observed blocked exits and stacked combustibles. The nature of fires involving sandwich panels is such that well rehearsed evacuation plans are essential.

(ii) Buildings need to be kept in good repair. Damage to sandwich panels can expose the combustible core, as can penetrations, eg for light fittings.

(iii) Staff may attempt to fight a fire without calling the brigade because of the effects of cold water on hot machinery which can prevent rapid return to production. There is a need for careful staff training.

(iv) Food factories, in particular, contain large quantities of combustible material as part of their business, as well as that contained within the sandwich panels. However, the fuel within the panels is not visible and the metal surface may give an illusion of safety. In addition, fires within panels are more difficult to fight than those in other, exposed, materials. Designers and managers may need to be made more aware of the materials contained within their buildings.

7.5 General issues

(i) The risks from sandwich panels in new buildings may be different from those in older buildings. Newer buildings will more probably contain the newer fire retarded products, and future buildings may be addressed through regulations. Existing buildings however may contain large amounts of combustible core panels and these will need to be addressed through fire safety management procedures and pre-planned fire brigade operations.

(ii) The need for hygienic conditions needs to be balanced against the need for fire safety. Clearly the two issues involve different aspects of public safety and must be reconciled.

(iii) It may be helpful to compare the role of polymer-filled sandwich panels with the role of the timber in timber-framed properties. In both cases there is a possibility of the combustible elements in the structure becoming involved in fire. In neither case will those combustible elements be involved as the primary source of fire except in very unusual circumstances.

(iv) The sandwich panel manufacturing industry appears to be developing safer products. The need for these is partly driven by the concerns of the insurance industry over the losses from the buildings containing sandwich panels, since often the building is destroyed.

(v) Other outstanding issues from this study include;

The need for guidance for the penetration of panels, eg for electrical fittings,

The use of extinguishers in cold stores,

The effectiveness of heat or smoke detectors in cold stores, where there may be forced air currents and/or water vapour,

The combustibility of materials at very low temperatures, where materials are very dry.

The effectiveness of dry sprinkler systems in very cold conditions.

8. RECOMMENDATIONS

(i) Education programmes for greater awareness of the potential for fire spread in sandwich panels need to be initiated for the brigades to use in conjunction with inspection of premises to be certificated. FRS is now able to provide material that can be used in this way, for example infra-red records of fire spread within different panels. The collection and use of building type data bases has proved itself of benefit.

(ii) Building owners and users must be encouraged to use a fire safety management approach to control matters such as hot working, waste disposal, protection of escape routes and general good housekeeping. Proper and relevant training of staff is also needed.

(iii) The appropriate and proper uses for the different types of panel needs to be defined so that users, designers, and the fire service may work to a common agreed standard. In particular, combustible core panels should not be used near hot working.

(iv) The implications for operational procedures must be addressed so that there is a co-ordinated national approach. A simple measure would be to label the panels as they are fitted so that any building user or firefighter will know what materials are present. Most work areas are white but a simple colour code might be used which could easily be seen in a firefighter's torch (eg fluorescent blue for polystyrene, pink for polyurethane and yellow for mineral wool.)

(v) There is a need for government and industry to work together to derive agreed approaches to the issue of the fire safety of sandwich panels. However, it needs to be recognised that the needs of life safety and the needs of property protection may not be the same. This joint approach is largely already in hand.

(vi) Further work is needed on the subject of fire safety of sandwich panels as outlined below.

9. PROPOSALS FOR FUTURE WORK

(i) Small-scale tests

The series of small-scale tests carried out as part of this programme should be continued to include the other types of panel in use.

(ii) Large-scale experimental work

Following on the small-scale work above it would be useful to examine the fire behaviour of representatively-sized panels with joint detail and connections of at least of 3m in the ISO test facility and the sprinkler-calorimeter. At this scale it would be possible to carry out extinguishing tests using water from hoses and sprinklers and other fire extinguishing media to examine the effectiveness of these media on fires shielded by the metal skin. There is also a need to examine delamination from heated panels even where the core is not burning but where the binder has softened.

(iii) Develop of a fire test.

There is a need to continue with the development of a method of assessment for sandwich panels.

(iv) Methods of fixing ceiling panels

The problem of delamination has been identified as a particular risk for fire fighters. Methods need to be considered that will prevent delamination without creating a cold bridge.

(v) Thermal imaging

The use of thermal imaging has proven a useful tool for fire fighters dealing with sandwich panel fires. This technique may need further development.

(vi) Development of labelling systems

As the tests above will generate much smoke we propose that we apply fluorescent strips to the panels reflecting their contents to check for visibility in a torch beam during fire tests.

(vii) Other outstanding issues in need of further study;

The development of guidance for the penetration of panels, eg for electrical fittings,

The use of extinguishers in cold stores,

The effectiveness of heat or smoke detectors in cold stores, where there may be forced air currents and/or water vapour,

The combustibility of materials at very low temperatures, where materials are very dry.

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ANNEX 1 - CONTRIBUTING BRIGADES

FRS wish to thank the following County Fire and Rescue Services for their co-operation and the information they supplied either in their responses to the Fire Service Inspectorate questionaire or through telephone conversations.

Brigade	Number of Premises using Sandwich Panels
Avon	250 premises to be inspected.
Bedfordshire	
Berkshire	
Cambridgeshire	
Cheshire	
Cleveland	8 food processing, 1 cold store, 4 supermarkets, 4 abattoirs, 1 dairy
Clwyd	
Cornwell	38 food processing, 5 food stores, 25 supermarkets.
Cumbria	
Derbyshire	10 premises
Devon	
Durham	
Dyfed	2 premises
Essex	30 premises
Mid Glamorgan	
West Glamorgan	2 premises
London Fire & Civil Defense Authority	
Greater Manchester	47 premises
Hampshire	
Hereford & Worcester	36 large users of sandwich panels
Hertfordshire	5 premises
Humberside	
Kent	
Norfolk	
Northamptonshire	60 premises
E Sussex	
Tyne & Wear	
West Midlands	
Isle of Wight	
Wiltshire	
North Yorkshire	
West Yorkshire	2 premises
Nottinghamshire	
Shropshire	9 premises, 15 to be inspected
Surrey	
Lothian & Borders	

ANNEX 2 - Photographs

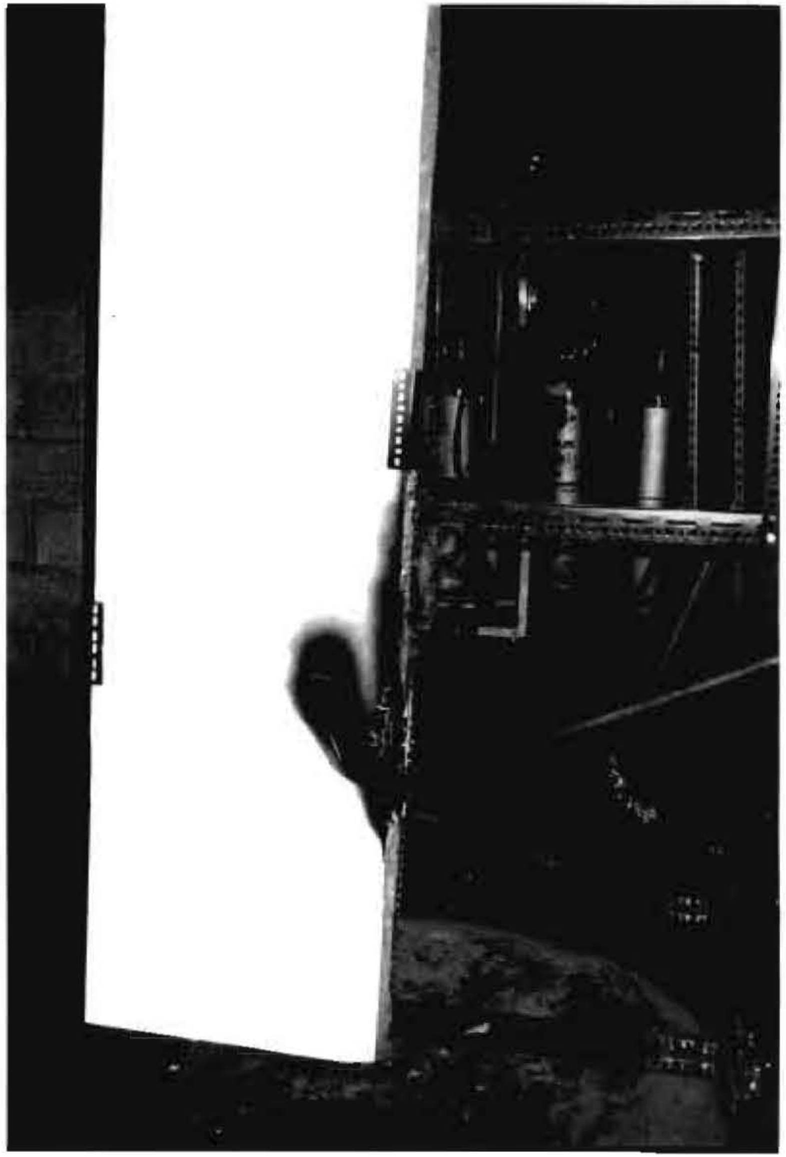
Mineral wool panel - during test and after

Polystyrene jointed panel test

Typical impact damage (from fork lift truck)

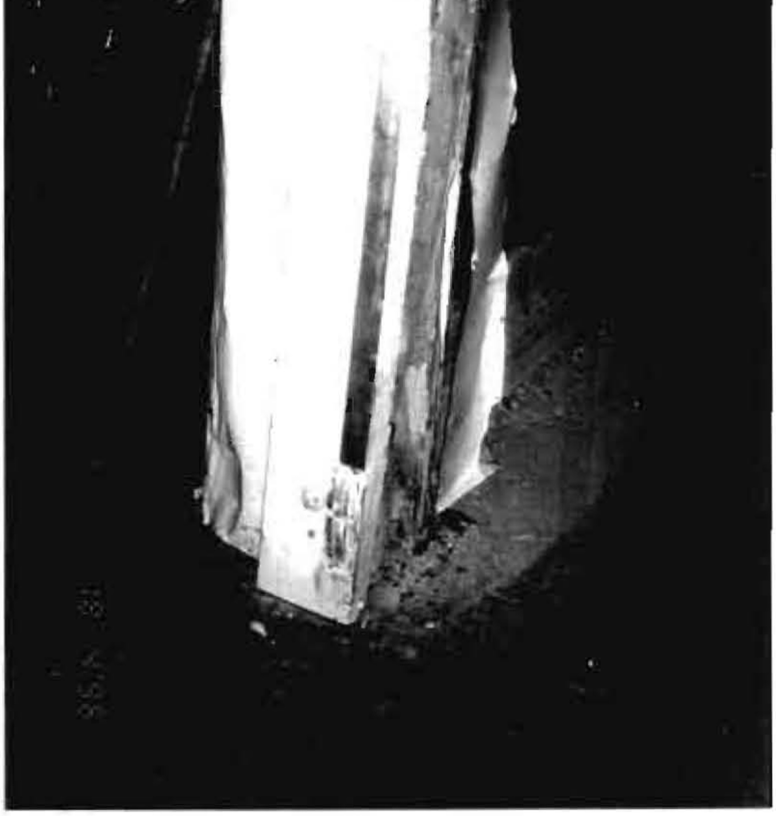
Exterior wall of building showing puncture.

Penetration of services through ceiling panels
Note ice build up on pipes.

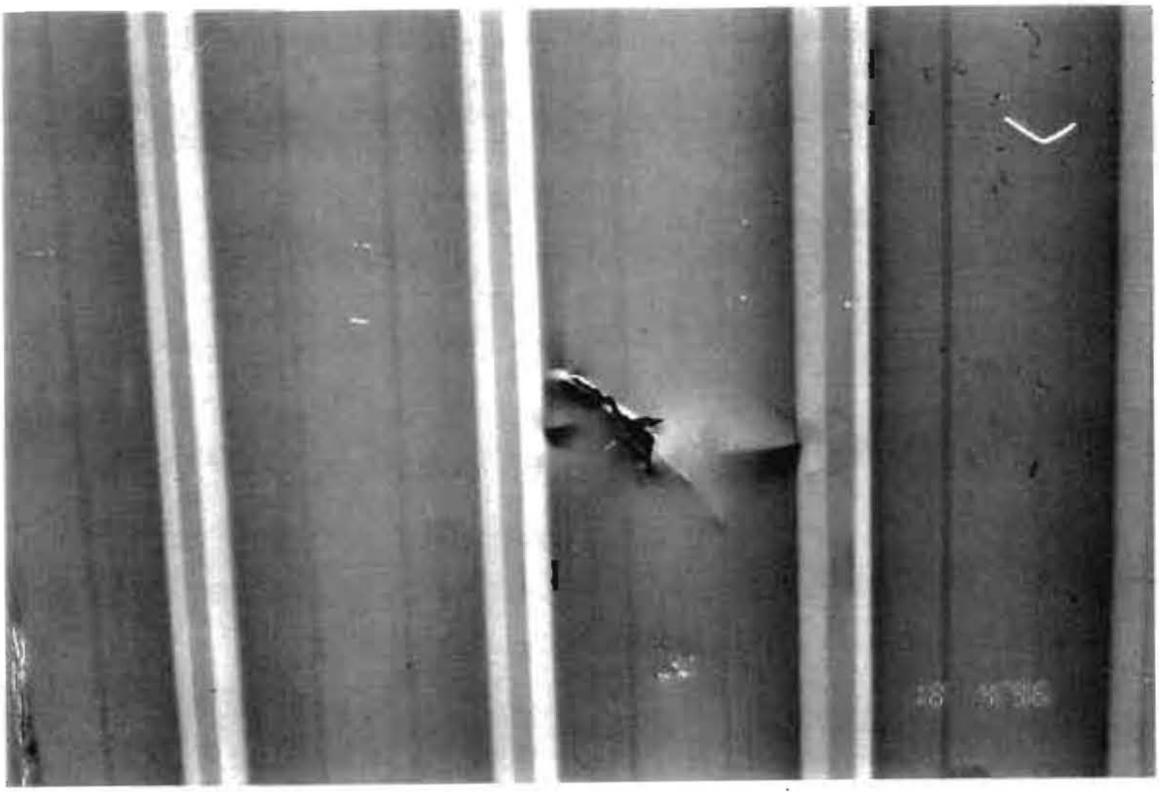


Mineral wool panel - during test and after

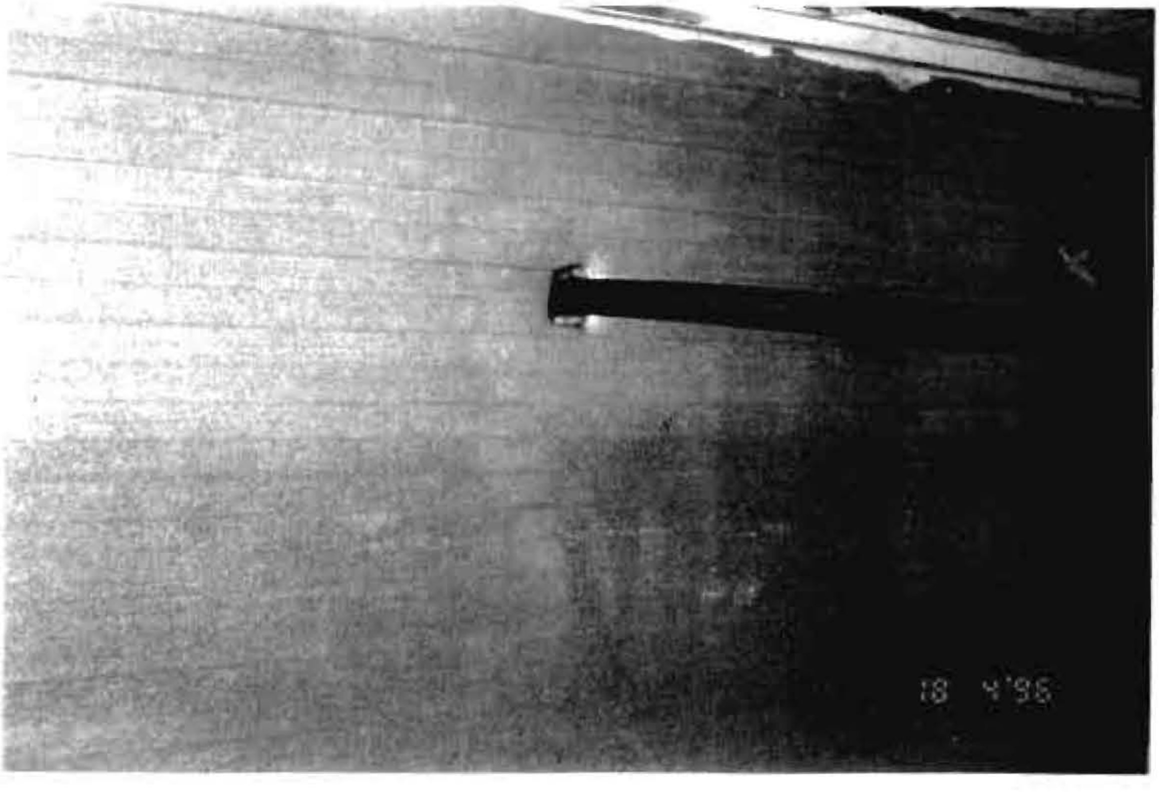
Polystyrene jointed panel test



Typical impact damage to door frame base (from fork lift truck)



Exterior wall of building showing puncture (from fork lift truck).



Penetration of services through ceiling panels
Note ice build up on pipes.