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This discussion of fire research empnasizes test procedures and architectural element performance. Measurement and simulation of fire conditions establish "fire load" specifications, structural influences, and corridor surface lining data. Topics studied include--(1) fire endurance of building elements, (2) material flammability, (3) material combustibility, (4) thermal decomposition products of plastics, (5) fire extinguishment, and (6) fire prevention and protection factors. A short forum discussion is included. (MH)

FIRE RESEARCH AT THE NATIONAL RESEARCH COUNCIL

By G. W. Shorter, National Research Council.

To speak on fire research to administrators of the physical plants of universities and colleges presents a special challenge to a speaker from the National Research Council. In the first place the National Research Council is keenly interested in schools of higher learning as evidenced by the fact that last year the Council spent over $34,000,000 on scholarships and grants in aid of research. Secondly the Council's concern for fire problems is shown by the support the Council provides for a program of fire research within the Division of Building Research. The National Research Council was established in 1916 and consists of the President, Vice-President (Administration), two Vice-Presidents (Scientific), and not more than 17 other members appointed by the Govenor in Council.

Council activities have continued to expand over the years, although substantial areas of research such as those associated with defence and atomic energy have been detached. The Council is not part of a government department, but instead is responsible to a designated minister who is a member of a cabinet committee on Scientific and Industrial Research. The main role of the National Research Council is to serve the secondary industry of Canada. Primary industry such as agriculture is served by research facilities maintained by the federal department concerned. At present the Council supports the work of 2200 university scientists and awards 1900 scholarships, bursaries and post-doctorate fellowships. It also operates its own extensive laboratory system which is served by a staff of 2800. The expenditure for these various functions during the past year was approximately $80,000,000. The capital investment in laboratory buildings and equipment is approximately $100,000,000. divided equally between buildings and equipment. The NRC laboratories are organized in ten divisions and two regional installations with the major laboratory facilities being located in the Ottawa area. One of the Divisions is that of Building Research.

The Division of Building Research was established in 1947 to serve the construction industry of Canada. The major laboratory facilities of the Division are located at the NRC Montreal Road site. The staff strength is 224 with the work being divided into two areas: Building Practice and Building Science. The Building Science sections are Snow and Ice, Soils and Foundations, Building Structures, Building Physics, Building Services, Organic Materials, Inorganic Materials and Fire Research.

The Fire Research Section was started in 1950 because fire was considered to be a national problem and one which the Division of Building Research should be concerned with. In carrying out fire research, emphasis has always been placed on field as well as laboratory studies.

The staff of the Section number 24 including an "industrial fellow" sponsored by the steel industry of Canada. The laboratory facilities are contained in a large building forming part of the Building Research Centre. The building covers an area of 20,000 sq ft and has a total cubage of more than 500,000 cu ft of which nearly half is made up of the volume of the 40 ft high structure housing the furnace laboratory and the burn area. Physics and chemistry laboratories are situated in the front wing of the building. There is a large area outside which provides an outdoor experimental site. The Section is essentially interested in building fires with the work falling into four broad categories which are: building fire performance, fire behaviour, reaction of materials and assemblies of materials to fire and fire extinguishment.

BUILDING FIRE PERFORMANCE

The Section continues to study the performance of buildings during actual fires. While investigating a fire, conditions influencing life safety are noted for future reference. Such information is frequently useful to building code committees. A statistical analysis of fire deaths in the province of Ontario was continued for ten years. This is a comprehensive study in which factors influencing fire deaths were analysed. A few of the findings of a recent report on fatal clothing and bed fires will now be presented. Of the 320 fatal clothing fires studied 102 were associated with the use of cooking appliances and 58 of the victims were women over 50. The mishandling of flammable liquids accounted for 51 deaths, with over 40% of the victims being adult men. The third largest group of 46 was associated with industrial incidents and the victims were all adult men with one exception. Smoking was the next highest group with 8 of the victims being elderly men asleep in chairs or chesterfields. Children playing with matches resulted in 22 deaths. Fatal bed fires accounted for 147 deaths with males outnumbering females 2.6-1. Nearly half of the victims were under the influence of alcohol, drugs or sedative. Almost all of the bed fire fatalities occurred in residential occupancies and in 66% of the cases the fire did not extend beyond the room of origin. A study has recently been initiated of conditions in high rise buildings as they affect life safety.

During investigations of fires attention is given to the influence structural features have had on limiting fire damage. The influence of lining materials on the development of fire is also a matter of interest. Another area examined is the effectiveness of compartmentation on restricting fire spread both vertically and horizontally. The effectiveness of compartmentation depends largely on the fire endurance of the enclosing elements. The fire endurance of such elements is determined by standard tests. In these tests fire severity has been related to the fire load in various occupancies. "Fire load" here means the amount of combustible material per sq ft of floor area. The greater the fire load the longer the duration of the fire. Recently an international survey of fire loads has been initiated in which NRC will take part. It is being undertaken because fire loads have probably changed since similar surveys were carried out in the United States a number of years ago. In carrying out this survey members of the Fire Section will estimate the amount of combustible furnishings, stock etc. in a number of occupancies. This information is of importance to those preparing building code requirements. For example, it has been suggested that a fire load of less than 5 lbs/sq ft will not seriously damage unprotected structural steel members.

FIRE BEHAVIOUR

Of recent years a good deal of attention has been focused on studying the development of fire in and between buildings. One international program is concerned with investigating the development of fire in compartments. Under "Conseil International du Batiment" (CIB) a models program has been underway for a number of years. Several countries have participated in this program, Part I is now complete except for the final analysis of results. This part of the program has been concerned with studying the factors influencing the duration of a fire. Box models of sizes up to a six-foot cube with various openings have been used. Fuel has been provided in the form of wood cribs, the size and location of which have been varied. Although the final report has not been issued it would appear that the duration is to a great extent ventilation-controlled. Commencing in 1967 the Fire Research Section will participate in Part II of the program which will be concerned with the factors influencing the development of a fire.

Several years ago the Fire Research Section initiated a project to investigate the influence of interior lining materials on the development of fire in a corridor. For at least twenty years tests have existed whereby materials can be given comparitive ratings so far as their spread of flame characteristics are concerned. How the results of such tests should be applied has been in some doubt, largely because the average room, hall or other compartment of a building usually contains sufficient combustible material to allow a fully developed fire to become established. The application of flame-spread ratings to fire spread in a corridor was considered for several reasons. Firstly the corridor is unique in that it can be designed to have very few combustibles in it and hence to be unable to sustain a fully developed fire. Secondly, the corridor is particularly important from the fire point of view in that it can be the path by which fire spreads. Thirdly, corridors usually serve as escape routes for occupants and access routes for fire fighters. The subject was first investigated several years ago on a small scale with a model corridor. It was found that fire involving the whole cross-sectional area of the corridor either decisively propagated to the end of the corridor or proceeded much more slowly and died out before reaching the end. Later a large scale (8 ft x 6 ft x 64 ft long) corridor was constructed. The test procedure was, as in the case of the small scale corridors, to subject one end of the corridor to severe fire exposure. In these latter tests the effect of floor coverings was found to be much less important than on the small scale. It has become evident that wall linings play a substantial part in spreading fire.

The development of fire within buildings, particularly with reference to the movement of smoke is being studied. Case histories of fires, especially in high buildings, where smoke has been a problem are being collected. Pressure measurements are being made by another Section of the Division in several tall buildings to study ordinary air movement in these buildings. Expressions have been developed to describe smoke movement within buildings and suggestions have been put forth for controlling smoke movement by establishing pressure differences.

The spread of fire between buildings has also been investigated by the Fire Research Section. Several buildings located in an area to be inundated as a result of the St. Lawren Seaway development were burned during the winter of 1958. This operation, known as the St.Lawrence Burns, provided a good deal of information on the spread of fire by radiation. Measurements were made of radiation intensities at various distances from the burning buildings. This information allowed tables to be prepared setting out spatial separation requirements in the National Building Code (1960). There have been several refinements to the technique for ascertaining satisfactory spatial separations but all of these have been based on information developed during the St.Lawrence Burns. Studies at actual fires have also provided evidence of the validity of the N.B.C. spatial separation requirements.

In confining fire within a building or between buildings much reliance is placed on the fire endurance of the structural and enclosing building elements. To evaluate the fire endurance of materials and assemblies of materials is a major responsibility of the Section.

FIRE ENDURANCE

In order to carry out this responsibility the Fire Research building includes a large furnace laboratory 40 ft x 120 ft x 40 ft high. The major pieces of equipment in this laboratory are a wall furnace (specimens up to 13 ft x 14 ft) and a floor furnace (specimens up to 12 ft x 15 ft). There is a large area set aside for conditioning specimens. A 30 ton crane is used for moving the specimens and their frames. These large scale furnace facilities are used both for research and commercial tests. The fire endurance of building elements is determined by exposing them to prescribed heating and loading conditions. Both furnaces are heated by propane burners, the fuel input to which is automatically controlled. The temperature in the furnaces must follow a specific time-temperature curve. For example, the temperature at 5 mins must be 1000°F and at the end of 1 hr must be 1700°F. Special loading equipment involving hydraulic jacks is used with both furnaces. The criteria that determine the fire endurance of a specimen are as follows: Load-bearing specimens, such as beams and columns, must not collapse during the fire tests. If specimens, represent enclosing elements such as walls and floors then (a) no cracks or fissures must appear which would allow hot gases through and (b) the temperature of the unexposed side must not rise more than 250°F above the ambient temperature. The principal requirement for fire doors is that they stay in place.

Two small scale electric furnaces accommodating specimens approximately 30" x 30" are available for the development of new materials and assemblies of materials by industry. These furnaces are heated in accordance with the standard time-temperature curve but have no provision for loading specimens. They provide a reasonable evaluation of the thermal performance of building materials or assemblies of building materials.

Mathematical techniques have been developed by which the heat flow through a construction and its mechanical deteriotion during a fire can be estimated. The techniques are only appropriate when the physical and mechanical properties of building materials at elevated temperatures are known. A number of studies concerning the properties of such materials at high temperatures have been undertaken.

The lack of information concerning the creep characteristics of structural steel at elevated temperatures has prevented a full understanding of the behaviour of steel structures in fire. To eliminate this difficulty in cooperation with the Canadian steel industry, a comprehensive research program has been undertaken. The creep of three widely used structural steels has been studied at various temperatures and stresses.

Dilatometry is the measurement of the expansion and shrinkage of building materials during heating and cooling. Using a dilatometer, dilatometric curves are obtained for various materials. Quantitative information is derived from dilatometric curves regarding the coefficient of apparent expansion or shrinkage of a material at various temperatures. From these data the liability of a material to spall, crack or disintegrate during fire exposure and its probable behaviour after the exposure can be evaluated. This technique may be used in assessing the damage suffered by building materials during a fire. The Section has investigated the stress-strain behaviour of materials using a universal testing machine equipped with an electric furnace. Various materials have been tested in this apparatus under varying load and temperature conditions. Equipment for determining the thermal conductivity of building materials has been designed and installed in the Fire Research Section. In a series of tests the thermal conductitivy of various concretes and their constituents have been examined. One part of this investigation was concerned with the effect of moisture content on the thermal conductivity. The thermal decomposition of a number materials including plaster and cement paste has been investigated using thermogravimetric analytical equipment. Various materials exhibit characteristic curves which illustrate, for example, the progress of dehydration of portland cement during heating.

A computer is being used for studying one and two dimensional heat flow problems. Computer programs have already been developed for studing the fire endurance of concrete masonry units and the effect of moisture on fire endurance. Statistical analysis is used to evaluate performance of building elements in fire from tests results of similar materials or assemblies of materials.

The ability of building materials to spread flame on their surfaces is an important characteristic of such materials.

FLAMMABILITY

Recently the Section has installed the equipment necessary for carrying out flame spread tests in accordance with Method E84 of the American Society for Testing and Materials. This is the tunnel test developed by Underwriters' Laboratories Inc., Chicago, Ill. The test specimen which is approximately 25 ft x 18 in. in size forms the ceiling of the tunnel. A gas burner at one end provides the igniting flame. The time for flame to travel the length of the specimen, is measured. In this test asbestos cement board has a flame spread rating of 0 and red oak a rating of 100. The fuel contribution and smoke production of a material may also be evaluated.

A useful piece of flame spread equipment is the small radiant panel apparatus developed at the National Bureau of Standards, Washington, D. C. A specimen approximately 6 in. by 18 in. is placed at a slight angle to a gas-fired radiant panel. In this test the flame front progresses downwards. A flame spread rating is obtained from an expression involving both rate of progesssion of the flame front and peak rate of emission of heat. The ratings obtained from this test roughly correspond to those obtained using the large tunnel. Industry uses this facility a great deal for research and development purposes. During the past year it was used extenisvely to evaluate the flame spread of materials being installed in Expo buildings.

Another piece of test equipment recently installed is that for testing roof coverings in accordance with ASTM E108. There are three different tests involved in this procedure: 1) Intermittent Flame Exposure 2) Spread of Flame Test 3) Burning Brand Test.

During the last year an ad hoc experiment was used to investigate the vertical spread of flame on combustible cladding materials. Various materials such as cedar shingles, shakes, brick siding, vertical wood siding, clapboard, plywood, etc. were applied to furring strips fastened to a concrete block wall. A flame was applied to the bottom of the cladding until it was well ignited. Observations were then made of the degree of flame propagation upwards on the specimen.

The combustibility of building materials is also a matter of concern.

COMBUSTIBILITY

The Section has three small cylindrical electric furnaces which are used for carrying out combustibility tests under ASTM, CSA or BSI test methods. All these methods involve heating small specimens 1 1/2 in. by 1 1/2 in. by 2 in. at a constant temperature of 750°C or 1382°F. In addition to the above test there is another under consideration that would measure the heat contribution of a material using calorimetry.

The increasing use of plastics raises the possibility that when involved in fire they may yield both smoke and toxic decomposition products in quantities sufficient to produce a dangerous atmosphere.

## THERMAL DECOMPOSITION PRODUCTS OF PLASTICS

The Fire Research Section has participated in a round robin series of smoke evaluation tests sponsored by the American Society of Testing and Materials. These tests are being undertaken as part of a program to develop a satisfactory smoke evaluation test. The Section has initiated an investigation on the thermal decomposition products of various plastics. Polyvinyl chloride (PVC) was decomposed at three different temperatures, firstly in a inert atmosphere and secondly in air. Gas chromatography was the principal method used for the analysis of products. The main decomposition products were hydrogen chloride, carbon monoxide and carbon dioxide. Neither chlorine nor phosgene was detected.

## FIRE EXTINGUISHMENT

For several years the Section has worked on the development of a portable steam-inert gas generator. In this device a stoichiometric mixture of propane and air is burned and the gas produced is then cooled with a water spray. The resulting mixture of steam and inert gas having a low oxygen content and a temperature around $200^{\circ}F$ is an effective fire extinguishment agent. Concurrently with this development has been an interest in high expansion foam. In May of last year a series of tests involving both inert gas and high expansion foam were carried out by the Fire Research Section in the fire test building of the Ontario Fire College. The results provided further experimental evidence of the effectiveness of these methods of fire extinguishment.

The main purpose of fire research is to advance knowledge in fire prevention and fire protection. Several fire prevention and fire protection features of importance in the design and operation of buildings are now discussed.

## FIRE PREVENTION AND FIRE PROTECTION FACTORS

In any building it is important that every effort be made to prevent fire. University buildings are not unlike other buildings; they are in general exposed to the same common fire hazards such as the careless disposal of smoking materials. However with increased emphasis on research laboratory facilities special hazards have to be taken into account for example the use of proprietary pieces of equipment by a research worker. Although the worker may have had many years of training and experience in certain disciplines he still may not understand the functioning of such equipment. The hazard arises when the equipment is used under circumstances the manufacturer did not intend. Merely leaving equipment switched on unattended overnight can often create a hazard.

One or more of the following measures is usually necessary in the case of electrical or electronic apparatus: Individual fusing of sub-circuits within individual units, thermal cut-out devises and physical isolation of the apparatus from other combustibles to avoid propagating fire. These measures are most appropriate for computer facilities several of which have already been involved in serious fires. In Spite of all efforts to prevent fire, statistics have shown that it is not unlikely that one will occur. Therefore it is desirable to incorporate fire protection features when designing a building which will minimize the effect of a fire. One such feature is fire detection equipment.

There are many fire detection systems on the market. They are generally classified by the principle on which the detector head operates. Until recently two broad categories of detectors have existed, one responding to change in temperature and the other to change in the smoke level of the surrounding atmospheres. Of recent years a products-of-combustion detector has come on the market. The functions which detectors can and should perform are numerous. Conventional functions include the alerting of the occupants of a fire, the alerting of the fire department and the initiation of fire-fighting measures such as automatic sprinkler systems. Further possible functions include the activation of systems for closing doors and dampers in ducts and switching off mechanical ventilation equipment in the event of fire. The detection system might also ensure the automatic injection of fresh air into stairwells to keep them relatively free of smoke and the automatic venting of certain rooms in a building. In building design it is generally assumed that in spite of all precautions fire will start which will continue to develop. It is extremely important that the designer arrange for the confinement of a fire to the area of a building in which it originates.

Compartmentation of a building is probably the single most important fire protection feature in building design. Effective compartmentation will not only confine a fire to the area of origin but will keep escape routes such as corridors and stairwells relatively free of smoke. If compartmentation is to be effective then the structural and enclosing building elements must have the fire endurance necessary to withstand the fire load they will be exposed to. The use of highly flammable interior lining materials particularly in corridors should be discouraged as this type of material will increase the rate of development of a fire.

In summary it can be stated that knowledge in the fields of fire prevention and fire protection has increased significantly in the last 25 years. This increase is due largely to the information developed by fire research groups working in many different countries. If the knowledge now available was universally used by designers the number of large loss building fires could be decreased significantly. Therefore with proper design the physical plants of universities and colleges should be relatively immune to serious losses due to fire.

MR. ARMOUR: Thank you for a most interesting paper. I hope that it will generate some questions from the audience, I am sure that Mr. Shorter will be pleased to answer.

MR. HASTIE, UNIVERSITY OF TORONTO: I wonder if Mr. Shorter sould comment on library fires? Is there anything else than sprinklers? They are a little useless in a book room.

MR. SHORTER: With a library fire, I think one has a number of choises. I know sprinkler systems are a problem, however there are those who would argue that a small fire will be kept small by them. Another thing is compartmentation, if you can arrange it effectively; this is certainly a very important factor. By that I mean that you should have doors that will close in the event of a fire and then only one area will be involved. I would suggest one extension to this and that is detection. We now have very precise detection equipment available and I think they sould also be considered to detect a fire in a library at the earliest opportunity. Books do not burn easily.

MR. PALMER, ALFRED UNIVERSITY: We have a lot of people telling us that our sprinkler system should be tested, but no-one can tell us how to do it. Do you have a suggestion?

MR. SHORTER: I do not have any suggestion, but I would suggest that you get in touch with the sprinkler companies themselves.

MR. MCKAY, UNIVERSITY OF TENNESSEE: I have read that it is possible to put fire detection devices in the return air ducts, but I do not know how this is done?

MR. SHORTER: I have no idea how to put them into ducts; there are a lot of problems.

QUESTION: There are a variety of extinguishers, but most of them only act on one certain type of fire. Do you know of an all purpose extinguisher?

MR. SHORTER: On ordinary fires I do not think there is anything like water. But in special hazards in laboratories etc., I would suggest that you consider an all purpose.

MR. HERTENSTEIN, CALIFORNIA INSTITUTE OF TECHNOLOGY: You alluded to fires in buildings. Can you describe some of these?

MR. SHORTER: There were three where materials, construction materials and lining materials and lining materials, played a part. As far as the damage, I do not have details here but I can supply you with them. One of the problems we have found is smoke, and the fire is more significant due to the smoke. We have a number of examples of equipment just being left on.

MR. MCGUIRE, UNIVERSITY OF MAINE: You made a comment on carpeting in corridors. Would you care to elaborate?

MR. SHORTER: We are just taking part in a test on the kind of reaction. I do not know how big an effect this has. When we did our work in the small corridor we came up with more significant factor for floors than in the small scale. I think floor coverings tend to be the least bothersome. The effect of wall linings can be quite serious. In the corridor itself we had a fire at the end and it spread by the lining.

MR. SHORTREED, UNIVERSITY OF WESTERN ONTARIO: Some of our staff have commented they do not want to be exposed to ionised gases. I wonder if Mr. Shorter would comment?

MR. SHORTER: I can tell you that I have never heard it mentioned before, but it would certainly be useful to get it measured. I do not think it is a problem.

MR. SMITH, OHIO STATE UNIVERSITY: We have recommendations that we use fire retardant paint, particularly on ceiling materials. Is this effective?

MR. SHORTER: Yes. I think one has to watch the application. As far as new design goes it is probably something that is not encouraged. In older buildings I do not think there is much doubt that most of them would reduce the flame spread on the surface. At the same time, all that I know would not reduce the fire resistance on the ceiling and floor. Usually, if you use surface coating you must try and find out what is underneath and then you have the untreated side exposed.

MR. PALMER, ALFRED UNIVERSITY: Now that you mention paint, would you care to express your opinion on the paint manufacturers who should state that a particular paint was not inflammable but would not put this on the label of the can.

MR. SHORTER: Some of the solvents of fire retardant paints have to be watched.

MR. LAUDIERI, UNIVERSITY OF CONNECTICUT: Would you comment on the effect of suspended ceilings on the spread of fire in corridors and rooms? I mean the type of ceiling that is suspended by aluminum frames perhaps one-third of a foot below the regular ceiling. It is more a beautification of old buildings.

MR. SHORTER: The important thing is the flammability of that side of the material facing the air space. In most of my experience this is where the problem is. If you have material that is treated on one side, the fire can spread on the side which is not treated.

MR. ARMOUR: Are there any more questions? I would ask Mr. Morgan to thank the speaker.

MR. MORGAN: We certainly appreciate your coming to our meeting to-day and we certainly enjoyed your very interesting and informative paper. Thank you once again.