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DIVISION OF BUILDING RESEARCH

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# TECHNICAL NOTE

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PREPARED FOR Inquiry and record purposes

SUBJECT IGNITION OF MATERIALS BEHIND COMMON 1/8-INCH-THICK WINDOW GLASS

## SUMMARY

It is shown that, if windows are continuously wetted and remain in place, it is most unlikely that materials within a building will be ignited directly by a fire in an adjacent building. Under laboratory conditions, window glass which was being continuously wetted down did not fracture when the wet face was exposed to high levels of radiation or to the flame from a Meeker burner.

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The N.F.P.A. Committee on Exposure Fire Protection is currently revising the suggested practice for the protection against fire exposure of openings in fire-resistive walls. The Committee would like more information on the extent to which window glass will prevent the ignition of materials. The principal mechanism which would produce ignition is heat transfer by radiation and the question resolves itself into three parts, all concerned with radiation.

The first part relates to the level of radiation which can be safely tolerated at the surface of a combustible material, and the levels which might be incident upon a window. The second concerns the transmission of thermal radiation by window glass, which can be computed from existing data. The third part of the question is the likelihood that thermal stresses will fracture a window causing some or all of it to fall out. A small amount of experimental work on this latter subject has been carried out at the Division of Building Research of the National Research Council.

## RADIATION LEVELS

When discussing the likelihood of combustible materials' being ignited by a radiant flux, two levels of intensity prove to be particularly significant. The lower one, 0.3 $cal/cm^2/sec$, is the level below which most cellulosic materials cannot be ignited in the presence of a pilot flame (1). The higher one, 0.8 $cal/cm^2/sec$, is the level below which the spontaneous ignition of most cellulosic materials will not occur (1). The behaviour of unfinished, untreated wood fibreboard does not conform to the above generalizations, but in the present context it would seem acceptable to exclude this consideration. In fact, although the findings relate to cellulosic materials, they can be treated as generally applicable in the present context.

Although the lower level hardly seems relevant in the circumstances considered, it has been mentioned because of a somewhat surprising phenomenon which can occur if an enclosure is irradiated through a small opening. It has been found that, after long periods of irradiation, spontaneous ignition can occur with intensities very little higher than 0.3 $cal/cm^2/sec$. Time scales of the order of half-an-hour to an hour are involved, however, and it is to be hoped that such exposures would be the rare exception rather than the rule.

For the purposes considered here, therefore, it will be assumed that the maximum intensity of radiation which may be permitted to pass through a window opening is 0.8 $cal/cm^2/sec$. Subjected to higher intensities, materials could be expected to ignite within a period not greater than 10 minutes.

The attenuation of radiation by window glass (and water) is highly dependent on the spectral distribution of the radiation. This in turn is dependent on the absolute temperature of the source so that this factor must be included in a discussion of the radiation incident on the window glass of an exposed building.

The most severe exposure that could occur would be if a thick body of flame were to play on the window continuously. Any flame thickness greater than some 2 to 5 ft could be considered infinitely thick in this context for the flame would then have an emissivity factor of unity. Flames of thickness less than 2 ft would constitute much less of a hazard.

Except in the most exceptional circumstances (e.g. when large quantities of oxygen might be involved), both the absolute and the black body temperatures of the flames emanating from burning buildings will be less than 1000°C. In fact, even within burning buildings, these temperatures do not usually exceed 1000°C (2, 3) except in some cases of fires of long duration (e.g. 3 hours) in highly fire-resistant buildings.

The maximum level of radiation that can exist where temperatures do not exceed 1000°C is 3.6 cal/cm$^2$/sec; it will be assumed that such a level can occasionally be incident on the window glass of an exposed building. It exceeds the level that is tolerable on most combustible materials by a factor of 4.5.

## THE BREAKAGE OF WINDOW GLASS BY THERMAL RADIATION

When exposed to radiation, window glass will absorb some of the incident energy and hence its temperature will rise. This mechanism will take place to the greatest extent at the exposed surface. A rise in temperature will, in turn, attempt to produce dimensional changes and fracture will occur when the pattern of dimensional changes to be established becomes geometrically impossible. In place of dimensional changes, stresses known in this case as thermal stresses are set up and are responsible for the familiar cracks that occur.

A situation that would be conducive to breakage would be to irradiate only a finite square area of a large pane of glass. Without examining the conditions analytically it is obvious that the necessary dimensional changes needed to avoid stresses cannot be established, say, at the corners of the irradiated area. Fracture, in fact, begins at these corners. Theoretical analysis of a problem such as this would be extremely tedious and the subject was therefore examined experimentally.

Common 1/8-in.-thick window glass was irradiated by a 1-ft-square gas-fired radiant panel operating at an absolute temperature of about 950°C and a black body temperature of about 850°C. In the first instance the glass was not protected in any way and areas 3 in. square and 6 in. square of 1-ft-square pieces of glass were irradiated. In both cases fracture occurred with intensities only slightly higher than 0.1 $cal/cm^2/sec$.

It was therefore concluded that unprotected common window glass is unlikely to offer much protection against levels of radiation sufficient to ignite common materials. It was thought more profitable to investigate the likelihood of the breakage of window glass which is maintained wet on one surface.

The glass was sprayed with water on the unexposed surface and with a radiant level of 1 $cal/cm^2/sec$, breakage occurred on one of four occasions when a 6-in.-square mask was used. Detailed investigation of the performance of the glass using various areas of irradiation was unfortunately not possible owing to the limited size of the panel. With smaller exposed areas, breakage did not occur and the experimental arrangement made it impossible to obtain higher levels of radiation.

The effect of allowing diffusion flames, from gasoline fires, to play on the glass was examined briefly. Glass 1/8 in. thick was held at an angle of 45° directly in the flames, and water was played on the uppermost (unexposed) surface. Flames from a 4-in.-diameter tray failed to break the glass, but when an 8-in.-diameter tray was used, fracture did occur.

The more practical case of maintaining the exposed surface wet was then examined. The glass did not crack under any of the following conditions: (a) irradiation of various areas at the maximum level available (1 $cal/cm^2/sec$), (b) exposure to various diffusion flames and to the premixed flame of a Meeker burner.

It should be noted that, when the glass was subjected to the above conditions, the rate of flow of water necessary to maintain a continuous water film was about twice that normally necessary. When a wetting agent was added to the water, the above statement was still found to apply although lower flow rates proved to be adequate.

## TRANSMISSION OF WINDOW GLASS

The transmission characteristics of any 1/8-in-thick (nominal) window glass purchased in North America will usually be of the nature illustrated in Figure 1, which relates to incident radiation that is normal to the surface. The feature that will most influence the transmission of thermal radiation will be the sharp cut-off at about 2.7 microns and, for this reason, the curve may be represented without serious loss of accuracy by the broken line given in Figure 1. By combining this curve with a knowledge of the spectral distribution of radiation from a source at a chosen temperature, the transmission of the radiation from this source can be readily calculated. Tables of Planck's Radiation Functions are a convenient source for the spectral distribution information.

This approach relates only to a parallel beam of radiation which is incident normally (perpendicularly) on a sheet of glass. Attenuation, however, can increase substantially with increasing angle of incidence. Rather than list values for various angles of incidence, results have been derived for the more interesting case of diffuse radiation. To achieve this without becoming involved in a substantial program of computation, reference was made to a correlation by Mitalas and Stephenson between the transmission by window glass of normally incident radiation and the transmission of diffuse radiation (4).

Table I lists the results for three temperatures together with the radiation levels at black body sources at these temperatures. It is apparent that when thick bodies of flame surround a window, the attenuation it provides will not be quite sufficient to reduce radiation levels at the far side to values lower than 0.8 cal/cm$^2$/sec.

TABLE I

THE TRANSMISSION OF 1/8-IN. WINDOW GLASS

| Source Temperature, °C | Transmission % | | $\sigma T^4$ |
|---|---|---|---|
| | Normal Incidence | Diffuse Radiation | cal/cm$^2$/sec. |
| 900 | 35 | 31 | 2.56 |
| 1000 | 40 | 36 | 3.56 |
| 1200 | 49 | 44 | 6.37 |

## THE TRANSMISSION CHARACTERISTICS OF WATER FILMS

If common window glass is to remain in place when subjected to high intensities of radiation it must be kept wet. It is worth considering, therefore, the attenuating effect of a thin film of water.

The relevant information is not available in the form illustrated in Figure 1 in which the ordinate is in terms of over-all transmission including effects such as reflection at the bounding surfaces. Such a presentation was practical for glass because it is only available in a very limited number of thicknesses. To present absorption data regardless of thickness, an attenuation constant per unit thickness $\alpha$ may be listed (5). If absorption is then taken to be the only attenuating mechanism, and surface and diffraction effects are neglected, the attenuation for a thickness d, of n the material in question, will be $e^{-\alpha d}$.

A curve of $\alpha$ against wavelength, for water, is given in Figure 2. Its form makes its application in the present context very simple. Thus it has been shown in the preceding section that glass alone will provide a level of attenuation that is almost sufficient to protect materials from ignition. All that need be known concerning the water film, therefore, is whether its attenuation is appreciably greater than, say, a factor of 2.

Water film thickness measurements made in the laboratory suggest that even if wetting agents and pre-wetted glass are used, it is not practical to establish continuous water films with thicknesses of less than 0.3 mm. With such a thickness the attenuation of all wavelengths greater than 2.5 microns would be greater than $e^{+(100 \times 0.03)} = 20$. To all intents and purposes, therefore, all radiation beyond 2.5 microns would be absorbed by any water film.

Table II lists the fraction of radiation with wavelengths less than 2.5 microns for sources at three different temperatures. The values may be taken as conservatively maximal estimates of the fraction of radiation, incident on a water film, which will be transmitted.

TABLE II

RADIATION OF WAVELENGTH LESS THAN 2.5 MICRONS (FRACTION)

| Source Temperature, °C | Fractional Emission at Wavelengths less than 2.5 Microns, % |
|---|---|
| 900 | 26 |
| 1000 | 32 |
| 1200 | 42 |

As a rough check that no major factor had been omitted from the above analysis, an attenuation measurement was made using wetted 1/8-in. common window glass, and radiation from a panel at an absolute temperature of about 950°C. The wetted window glass was placed within an inch of the sensing element of the radiometer, while the whole assembly was something of the order of a foot from the radiant panel. The attenuation was by a factor of about 20, indicating that the water film (28 thou - 0.7 mm thick) played a greater part than the glass.

It is not necessary to proceed further to demonstrate that fire conditions on the wetted side of an 1/8-in. thickness of common window glass, continuously wetted by a water spray, are most unlikely to cause the ignition of materials on the far side of the glass, assuming that the glass remains in place.

## CONCLUSIONS

1) Provided irradiation periods are in terms of minutes and not hours, most materials commonly found within buildings will not ignite spontaneously when subjected to radiation levels of up to 0.8 $cal/cm^2/sec$.
2) It is feasible for flames from a burning building to subject another to a radiation level of 3.6 $cal/cm^2/sec$.
For a window assembly to protect materials from spontaneous ignition it is therefore necessary for the assembly to attenuate radiation by a factor as high as 4.5.
3) Radiation levels as low as 0.1 $cal/cm^2/sec$ are likely to cause common window glass to crack.
4) During the course of the laboratory experiments, 1/8-in. common window glass, continuously wetted on one side, did not crack when exposed, on the wetted side, to high levels of thermal radiation, to diffusion flames, or to the flame from a Meeker burner. The water flow rate necessary to maintain a continuous water film under these conditions was about twice the rate normally necessary. This finding also applied when a wetting agent was used although, of course, lower rates were then sufficient.
5) 1/8-in. common window glass, provided it remains in place and is continuously wetted by a water spray, will provide sufficient attenuation to ensure that materials within a building will not be ignited by heat transmitted through the glass and originating from severe external fire exposure.

It would be interesting to investigate the behaviour of certain borosilicate glasses to determine whether they could withstand fire conditions and provide adequate attenuation in the absence of a water film.

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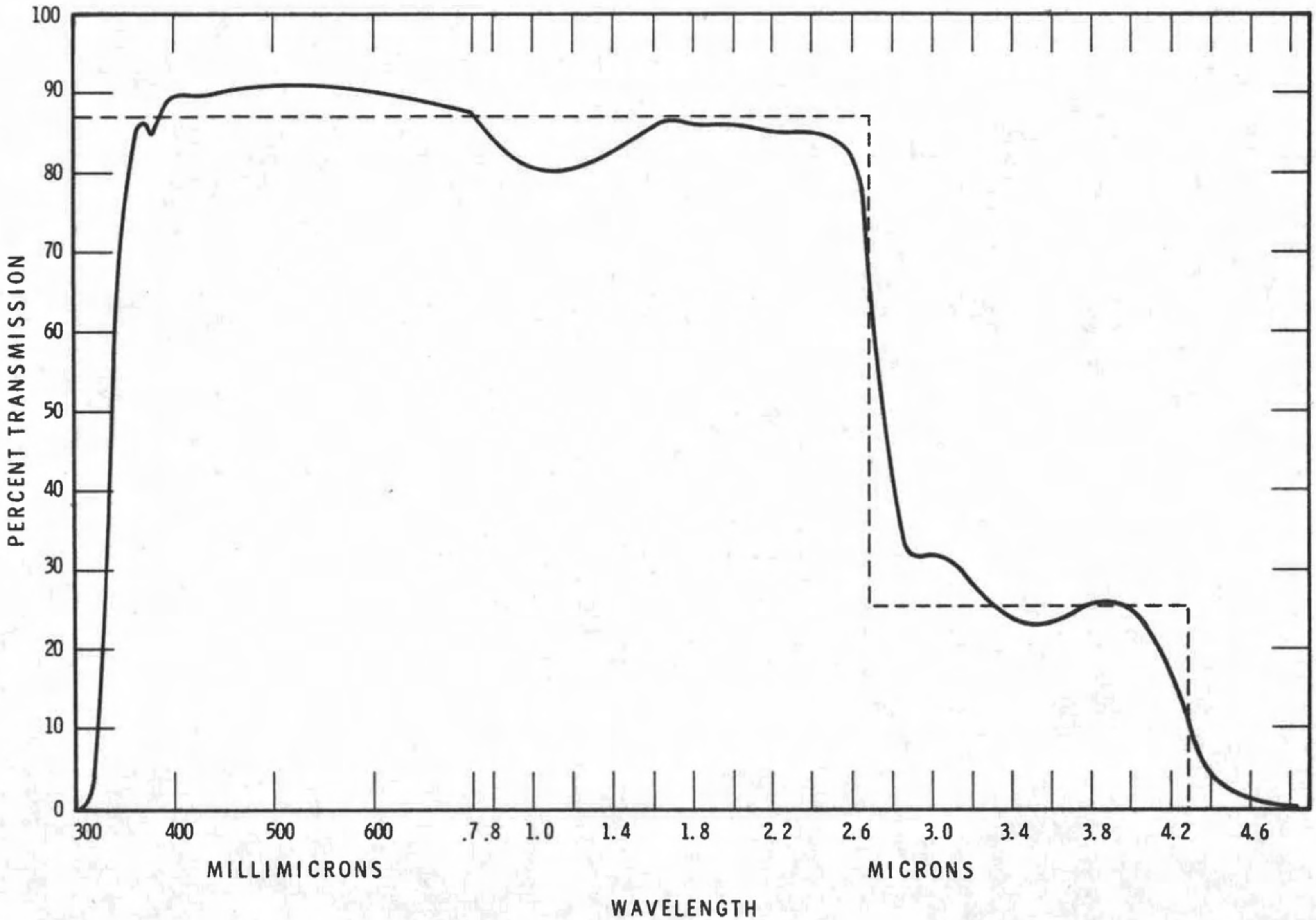


FIGURE 1

SPECTRAL TRANSMISSION OF 1/8" COMMON WINDOW GLASS

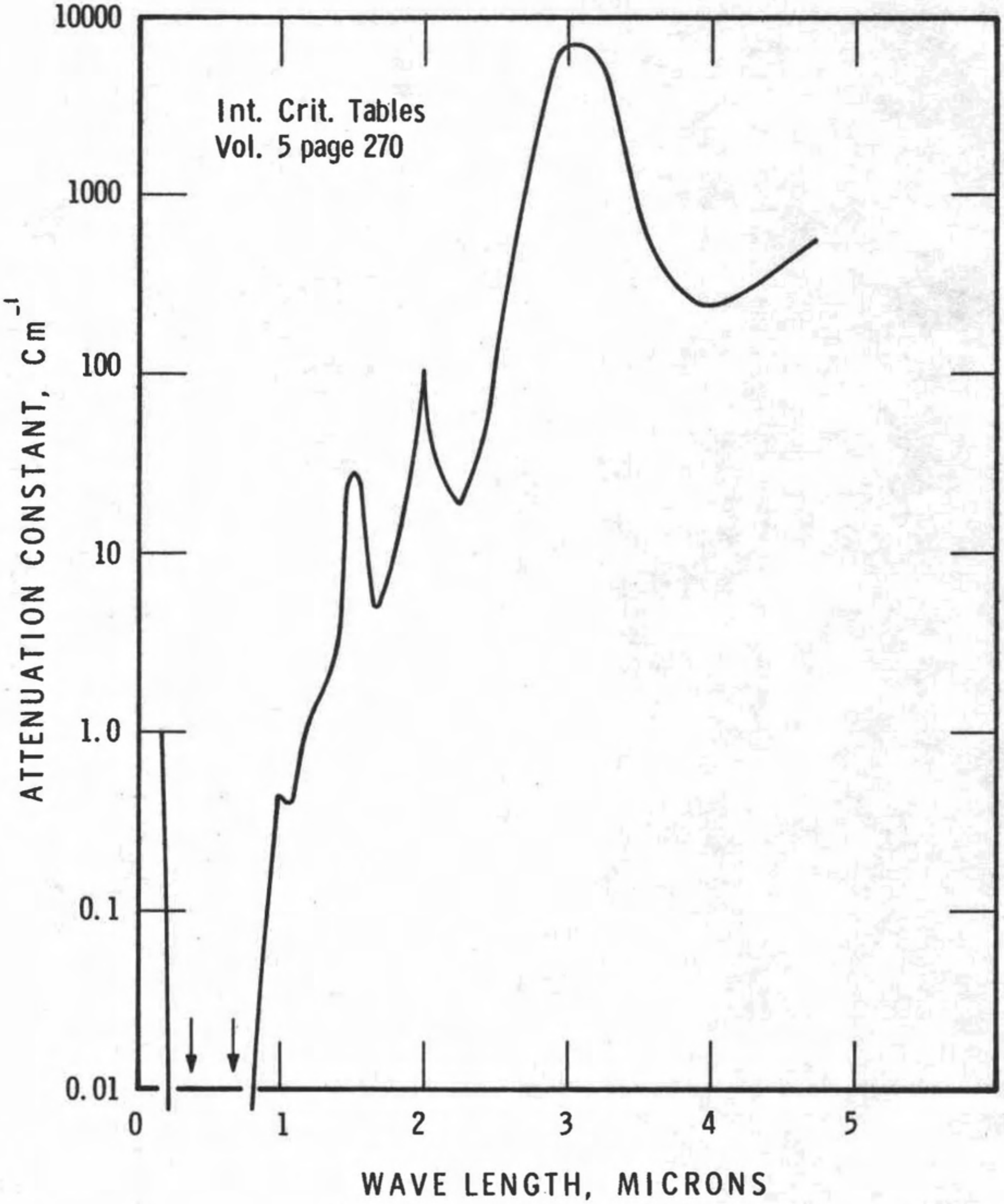


FIGURE 2

SPECTRAL ABSORPTION COEFFICIENT OF WATER