Test of the Severity of Building Fires

From its earliest years, NBS has had international leadership in the measurements, standards, and technologies associated with prevention of human suffering and losses of lives, property, and societal capabilities to unwanted fires. A major milestone in fire safety engineering, internationally, was publication of *Tests of the Severity of Building Fires* [1] in 1928. Its author was Simon H. Ingberg, Chief, Fire Resistance Section, U.S. Bureau of Standards.

Fire statistics published by the National Fire Protection Association [2] show that about two million fires are reported in the United States each year, causing 4000 deaths and 8 billion dollars in property damage. This is bad, but it used to be worse. Early in the 20th century, with a much smaller U.S. population, twice as many people died each year. At that time the fire death rate per 100,000 population was 9.1, in contrast to 1.6 today [2]. The buildings that burned in the early 1900s often collapsed as fire spread throughout the structure. Fire measurement at NBS quantified the intensity and duration of building fires. Simon Ingberg related the measured fire temperatures and duration to equivalent exposure to the standard furnace fire time-temperature curve [3]. Today's fire resistant construction is evaluated using the ASTM E119 standard fire exposure based on the same approach. Ingberg's work provided vital information about the relationship between fire severity as measured in full-scale room and building fire tests and endurance ratings in the standard test method. This provided the guidance for building codes requirements and design approaches for fire resistive construction to contain fire spread in buildings. Today, as a result of confinement, detection, and suppression fire protection strategies, most fires in buildings never grow beyond the room in which the fire started.

In Ingberg's own words:

> "One of the main objects of public regulation of building construction is to prevent undue hazard to life and neighboring property from fire. Fire exposure to buildings and building members arises from interior and exterior origins. The evaluation of the exterior exposure can be done with difficulty in quantitative terms, and the gradual accumulation of data from actual fires will probably continue as the main guidance in providing the proper protection. The present paper will deal mainly with methods of gauging the severity of fires resulting from the burning out of contents of buildings whose wall, floor, and column constructions are fire resistive to such an extent as to be capable of withstanding a complete burning out of building contents without collapse of major details. It is only when the problem is so confined that there is much possibility of obtaining experimentally quantitative information pertinent to the answer sought. The severity of fires completely consuming the combustibles of frame buildings and masonry-walled buildings with combustible interior construction is of interest mainly as it concerns the exposure to adjacent or neighboring buildings and the fire exposure on party and fire walls and on record containers. As it concerns the severity of fires in buildings with interior combustible construction protected with incombustible floor, ceiling and wall finishes, the present discussion will apply up to the limit set by the fire resistance of such protection.
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> Indications of the intensity of building fires have been obtained from fused metals and from general fire effects on materials on which information is extant as to their reaction to temperature or fire exposure such as in test fires. The fire ruins or reports of fires give, however, little information of the duration of the temperatures in any given portion of the building. The absence of data to enable constructions or devices giving a certain performance in the standard fire test to be applied as protection against fire conditions in buildings with as much precision as results of strength tests are applied for load carrying purposes, led me to consider the possibility of conducting burning-out tests in suitably designed structures to obtain the needed information. If such tests could be made to yield quantitative information on the equivalent fire duration to be expected with given building types and occupancies, it would help measurably to place the whole structure of fire resistance requirements on a rational basis. Fire is a contingent condition that may or may not involve a building or given portion thereof in its lifetime. In theory, at least, the owner should be required to make provision for safety to life within and near the building, and for protection to adjacent and neighboring property only as it concerns the building type and size proposed and the occupancy it is intended to house. With require-

ments more or less uniform for all occupancies the tendency would be to require more than the needed protection for buildings with the lighter occupancies from the fire hazard standpoint, and not enough for those with greater amounts of combustible contents."

Ingberg addressed these objectives by constructing two single-story fire test buildings on the NBS site of sizes 4.9 by 9.1 meters and 9.1 by 18.3 meters. Various arrangements of furnishing, shelving, and paper (discarded records) were used to assemble realistic representations of offices and records storage rooms (see Fig. 1 and Fig. 2, respectively). Tests included variations,

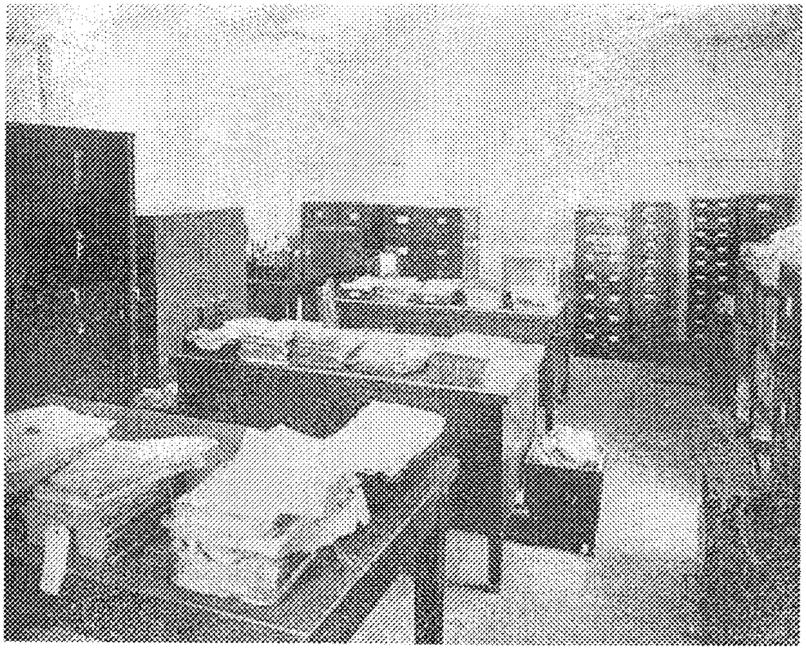

Fig. 1. The interior of the small test building arranged to represent a typical office with metal furniture on a cement floor. (Used with permission of NFPA.)

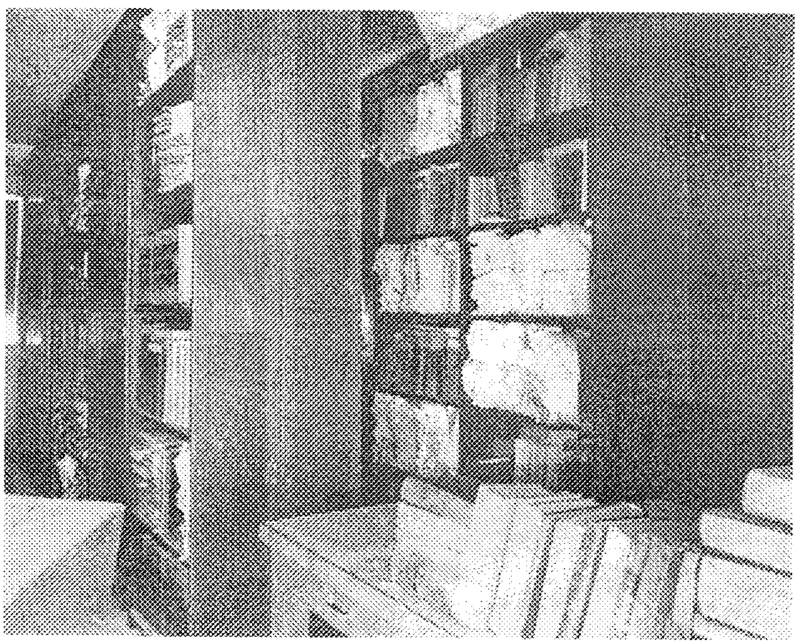

Fig. 2. Steel shelving in the small fire test building arranged to represent a records room. (Used with permission of NFPA.)

such as the use of non-combustible metal furnishings instead of wooden furnishings, to examine the change in fire intensity. Building ventilation was provided to maximize fire conditions by adjusting openings in windows (Fig. 3). Temperatures were measured at 35 to 40 points in the smaller building and 100 in the larger.

Results of ten large-scale tests were analyzed and tabulated to relate the combustible content (in terms of either mass or calorific energy per unit area) to the equivalent fire duration (in hours and minutes) of a standard fire furnace test exposure temperature curve. Except for the fact that average room temperatures in the fire tests generally increased after ignition, then decreased from a peak as fuel was depleted, the two curves were not identical in shape. So the challenge for Ingberg was to adopt a method for gauging the overall severity of a fire test relative to the standard fire exposure. He proposed that the area under the time-temperature curve, but above selected base-line temperatures, represented an approximate gauge of exposure severity. He recognized that this is an approximation, but that no better measure of comparison could be conveniently applied. This remains true today.

Ingberg's tests related severity of fires resulting from a total combustible content (including finished floors and trim) in offices and record rooms ranging from 49 kg/m^2 to 290 kg/m^2 to be the equivalent to standard furnace fire exposures of 1 h to 7.5 h, respectively. As a result of Ingberg's work, it became possible to develop fire codes and design approaches that related the combustible load in a room, based on its contents and use, to the performance of fire-resistant construction details in the standard fire test.

NBS under Ingberg's leadership continued to explore fire severity, including notable full scale tests in buildings near the corner of 10th and B streets, NW, in downtown Washington, DC, scheduled for demolition to obtain space to construct today's Justice Department Building on the Federal Triangle (Fig. 4). In 1928, this full-scale fire test of buildings ignited, then allowed to burn without application of water, was unique in the history of fire protection engineering. In the test conducted on Sunday morning, June 17, 1928, fire conditions in adjacent five-story and two-story brick open-joist construction buildings were measured for the purpose of comparison to the standard furnace exposure conditions and duration. In addition, the test gathered data about fire exposures to support test standards for fire resistant safes and other record containers.

It remained necessary to provide uniform fire-resistance classifications for building constructions as a sound basis for permitting the use of new systems of construction that could be demonstrated to be comparable in performance to systems prescribed by building codes. A Subcommittee on Fire-Resistance Classifications was organized under the auspices of the U.S.

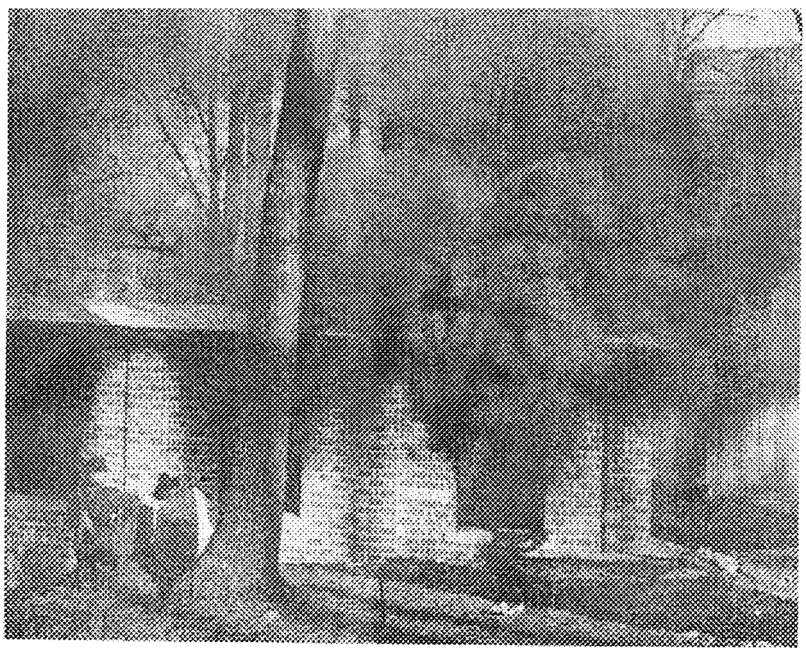

Fig. 3. Smoke billows from small test building on the NBS site through open windows adjusted to control ventilation in one of Ingberg's office occupancy fire test. (Used with permission of NFPA.)

Fig. 4. Burning test buildings near the corner of 10th and B Streets, NW, in Washington 10 to 20 minutes after ignition on Sunday morning, June 17, 1928. These burning buildings are on the present day site of the Justice Department Building. The Old Post Office building is in the background. (Used with permission of NFPA.)

Government's Central Housing Committee on Research, Design, and Construction. Subcommittee members were officials of federal agencies including Public Buildings Administration, Federal Housing Administration, United States Housing Authority, and Home Owners' Loan Corporation. Ingberg served as technical advisor to the subcommittee, led the program of research, and wrote its seminal report, *Fire Resistance Classifications of Building Constructions* [4] in 1942. The report contained:

1. A classification of four types of construction (Fireproof, Incombustible, Exterior-Protected, and Wood) covering the whole range of basic building construction properties that influence fire hazard.

2. Estimations of fire severity based on surveys of combustible contents of buildings housing typical occupancies.

3. Fire-resistance ratings of building constructions and fire-resistance classifications of roofing materials derived from analyses of test results at NBS and other laboratories.

Ingberg's work on fire severity and fire resistance was adopted by national standards and model building codes, which in turn became the bases for the legal building codes of local and state governments throughout the U.S. His principles and recommendations remain the basis for today's standards and building codes for determining the effects of combustible building contents and furnishings on the severity of fires for which buildings are required to be designed. His classifications of building types remain the basis for requirements for fire resistance of building components such as walls, floors, roofs, doors, and windows.

Simon Ingberg was born in Ringsager, Norway on June 24, 1877, emigrated to the United States with his parents in 1881, and grew up on a farm near Hendrum, Minnesota [5]. After finishing his junior year in high school, he taught in the public schools of Norman and Polk counties, Minnesota, for ten years prior to going to college. He received a B.S. in civil engineering from the University of Minnesota in 1909, and an M.S. in theoretical and applied mechanics from the University of Illinois in 1910. After 1 year on the faculty of Lehigh University, and work with a Chicago structural engineering firm, he joined NBS in 1914 as an associate physicist. His first assignment was to oversee fire tests sponsored by NBS at Underwriters' Laboratories in Chicago.

In 1915 Ingberg was placed in charge of a new fire resistance section in the Heat Division of NBS, and he traveled extensively for six years to oversee fire testing in Chicago and in NBS laboratories in Pittsburgh and Washington. These included studies of concrete and steel columns and development of a furnace for studying the fire resistance of wall panels. During the 1920s and 1930s, his studies included fire protection of steel columns; strength of brick masonry; influence of the mineral content of concrete on fire performance; strength of steel, iron, and wood at high temperatures; self-heating and ignition of agricultural products; test of carbon dioxide for fire control in buildings; fire hazards of vaults for nitrocellulose film; cigarette ignition of mattresses; the cigarette as a fire hazard; flame spread test methods; performance of fire detection devices; surveys of fire loads in buildings; severity of building fires; chimney fires; and theater proscenium curtains. Federal funds were limited, and only with industry support was it possible to conduct much of the fire resistance work.

Ingberg was told he had to retire in 1947 shortly before his 70th birthday. He did not stop work, but made his garage into a fire test facility, and continued to prepare papers with NBS colleagues as a guest researcher. From 1954 to 1969, he was employed as a consultant to Rohm and Haas Company, which was promoting the use of plastics in buildings. A part of his advice was the recommendation: "You should so conduct yourselves that when your products are involved in a disastrous fire, and they certainly will be, that there is nothing in the occurrence for which you must apologize." In 1963 ASTM gave Ingberg its Award of Merit, and in 1970 ASTM Committee E-5 on Fire Standards established the Simon Ingberg Award to recognize those who have continued outstanding accomplishments, like his, in advancing fire safety.

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