SFPE Classic Paper Review: Fire Behavior and Sprinklers by Norman J. Thompson

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IN 1964, THE National Fire Protection Association (NFPA) published a comparatively short volume (only 157 pages, cover-to-cover) written by Norman Thompson. Thompson had been the first President of the Factory Mutual Research Corporation (FMRC) and was the retired Director of Research of the Standards-Laboratories of the Associated Factory Mutual Fire Insurance Companies (this organization and FMRC are now part of FM Global). In a foreword to the book, Percy Bugbee, then the General Manager of NFPA cited his organization's reasons for publishing the book:

> "Here then is the book that explains the often overlooked fundamentals of fire behavior that are important to a thorough understanding of the capabilities of sprinklers ... is being published by NFPA as a valued addition to the literature of fire extinguishment and as a tribute to Mr. Thompson's competent and dedicated service to fire protection."

Thompson's audience was (and given the practical content of the book, still is) the practicing fire protection engineer. In his preface dated April 30, 1964, he eloquently summarized his objectives in writing the book as follows:

> "It is impossible to cover in detail by rules or standards every conceivable fire condition, but the fire protection engineer who is reasonably familiar with the factors influencing fire intensity and travel of resulting combustion gases, and who at the same time has a good knowledge of what sprinklers can or cannot do under practical conditions is fairly well equipped to analyze any fire protection problem to good advantage and thereby to recommend effective protection measures."

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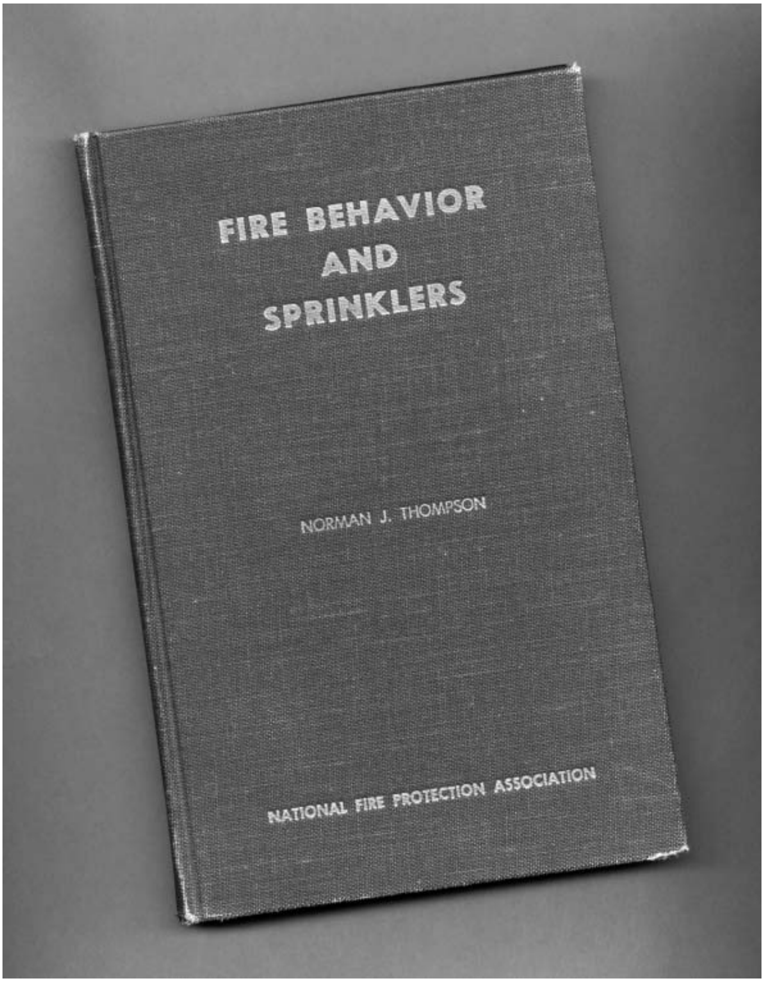

I started working at FM about 6 weeks after Thompson's book was published. There were many comments from my coworkers when the book was released since most of them knew Thompson and had worked with him for many years. By contrast, I was still very much in the process of learning just what fire science and fire protection was all about. As luck would have it, I would also never have the opportunity to meet Thompson – something I have greatly regretted over the years.

Thompson's successor, Jack Rhodes, with considerable help from the late Professor Howard Emmons, had just started FM's basic research program designed to investigate the fundamental nature of fire and fire suppression. Preliminary planning for a new large-scale test facility was also well underway. With all this activity, young engineers like me were gently prodded to read Thompson's book in the belief that it would help us become somewhat more effective, faster. As it turned out, not only was the book a good read, it also provided a great summary of the fire research that had been done until that time. Furthermore, it was loaded with practical information about industrial hazards and descriptions of practical engineering solutions to reduce those hazards. What I didn't know until I revisited the book almost forty years later for this review was that Thompson had identified many of the challenges fire research laboratories would have to resolve in the last half of the century (and continuing up to the present time) to truly advance the scientific basis of fire protection engineering.

The opening three chapters make up just about one-third of the book and describe the properties of various types of combustibles, the principal characteristics of fires – especially industrial fires – and the factors that affect fire intensity. Considered apart, these chapters today would likely be just a primer for nontechnical readers. In the context of the rest of the volume, however, they provide the foundation for more complex technical explanations of typical industrial fires and open the way for discussions on such design issues as fire growth and development and other factors affecting sprinkler performance.

Thompson also discusses the effects of heat transfer by radiation from combustion gases in the early chapters. The role of radiation in fire growth and development occupied a good portion of the early basic research undertaken by FM. This discussion also provides a good lead into the material in Chapters 4 and 5, where he discusses (to use today's terminology) the effects of ceiling jets and the performance of heat vents as a way of reducing fire spread. These chapters detail the classic experiments conducted in the so-called 'White House' at FM that, among other findings, led to developing the criteria used to minimize the combustibility of metal deck roofing materials. Thompson revisits these test programs later in the book when he discusses the affects of construction on sprinkler performance.

It isn't until Chapter 6 that Thompson arrives at the main topic of his book – automatic sprinklers. While much of Chapter 6 consists of the almost obligatory review of the development of sprinklers from the mid-to-late 19th century, it concludes with the more recently developed spray – or standard – sprinkler that by 1964 had supplanted old-style sprinklers in North America. At the time Thompson's book was released, the subtleties of testing sprinklers 'Centered under Four' or 'Centered under Two' sprinklers' were not widely appreciated. During the later development of early suppression fast response (ESFR) sprinklers, the importance of these different test criteria were of paramount importance.

Chapters 7 and 8 largely deal with the way in which sprinklers control fires and minimize temperatures in a building. Chapter 8 in particular provides very specific information on the response time of sprinklers under different conditions. Of particular interest is the analysis of operating times of standard sprinklers having different operating temperatures. The relationship between operating time and both fire-gas and sprinkler-link properties would later become of critical importance in the development of fast response links when Dr. Gunnar Heskestad developed the concept of 'Response Time Index' (RTI) a decade later.

In Chapters 9 and 10, Thompson addresses two of the most critical design characteristics of sprinkler installations: the effect of obstructions from building structural members or building components and the clearance between the sprinklers and the fire; and most critically, the subsequent penetration of sprinkler droplets through the fire updraft. While the discussion on clearance focused mostly on the relative performance of standard sprinklers as compared to old style sprinklers, the information on spray penetration is still pertinent today. For example, consider the following two sections from Chapter 10:

> "...it will be made evident from that large scale fire test data to show required water density cannot always be safely extrapolated to conditions of large clearances between sprinklers and combustibles, since such tests are usually run in a building of restricted area and with a low to moderate clearance between the ceiling and the fire."

and then, when discussing the relationship of sprinkler discharge pressure, clearance and penetration, Thompson writes:

> "While...distribution tests have been made at widely varying clearances between the sprinklers and the collecting pans, it was assumed that measurements under 'no fire' conditions would not be changed substantially with a fire in progress....This assumption has been proved to be far from correct..."

The chapter contains specific tests showing the relationship between these parameters under both fire and nonfire conditions. Even under nonfire conditions, the effect was dramatic. For example, with 25-ft. (7.6 m) high clearance from the ceiling to collecting pans located on the floor and at moderate pressures of 30–40 psi (207–276 kPa), between 60 and 70% of the sprinkler discharge never reached the pans. Losses increased to 80–90% at higher pressures. Further on, he reports on fire tests involving idle pallets where the effective weight loss of the pallet stack was essentially the same at clearances above 10 ft (3 m) even when the sprinkler 'design' density was increased 40–45% by raising the sprinkler pressure from 19 to 40 psi (131 to 276 kPa). Thompson's book coincided with the development of high piled storage and the likelihood of increased clearances from ceiling sprinklers to storages of varying heights.

It was these experiments perhaps more than any other that less than a year later ultimately convinced FM to construct the largest fire test facility in the world. The new facility allowed total ceiling heights up to 60 ft (18.3 m) and varying clearances from the sprinklers to the top of high-piled storage to better simulate emerging real-world conditions. Unfortunately, while sprinkler clearance was accepted as a real-world sprinkler design consideration, the deterioration of sprinkler penetration as a function of discharge pressure was not. By the end of the decade, computer technology permitted greater deployment of less costly hydraulically designed sprinkler systems using smaller diameter piping. Ceiling-level sprinkler discharge densities were achieved at lower cost than would have been the case with pipe schedule systems. What was lost, however, was water penetration to the fire because higher discharge pressures were usually required to achieve the needed discharge density. A review of Thompson's analysis might have resulted in more attention being paid to this important sprinkler performance area.

The next three chapters of the book deal with exposure protection from flammable liquid and flammable gas fires, a brief four-page discussion on water supplies and the effect of various construction types on sprinkler design. The discussion of exposure protection is a summary of one of FM's most extensive test programs on special hazard-type exposures. Many of today's special hazard sprinkler requirements are based on these half-century old tests. While the water supply chapter is largely obsolete today, the chapter on construction has an interesting discussion entitled "Occupancy – the Sole Criterion?." Thompson's text is almost apologetic that in all of FM's testing of fires involving simulated combustible construction, the conclusion was always that if the sprinkler system could handle the occupancy, there was a very small chance that the roof would become involved. In one sentence, however, Thompson presents a harbinger of the future when he states "In passing, it might also be noted that the resistance against collapse of roofs supported on modern very light bar joists is not even as good as board on joist roofs...." Subsequent loss experience from the midsixties involving light bar joist construction convinced FM to undertake several programs evaluating protection of steel from ordinary fires. These test programs substantiated Thompson's concern, making it critical to properly evaluate the thermal insult such buildings could receive from an occupancy fire.

Thompson's book concludes with a review of the 1963 edition of the *NFPA Standard for the Installation of Sprinkler Systems, NFPA No. 13*. Thompson's analysis of this standard covered all of the points raised in the earlier chapters. It also included some other suggestions that the engineering profession should always keep in mind when working on a code or standard: changing technologies. For example, Thompson cites several areas where occupancy, construction, water supplies, or production technology had changed dramatically but the sprinkler installation criteria had not been updated . . . including elimination of some long-standing criteria. Thompson concludes this overview by saying "It seems entirely possible that the Sprinkler Standard could be simplified and that many of its rules . . . could be eliminated." It is a testimony to the author that his vision was toward the future, a future that was based on scientific fundamentals, a strict view of the uncertainties of our engineering profession and a commitment toward continuous improvement of the technologies used to combat fire.

As a post script, after rereading this volume (and after forty years, a lot of it was new again) and never having met Norman Thompson, I asked Jack Rhodes and the late Bill Marsh (who headed Standards at FMRC) what kind of person he was. Both offered comments and anecdotes about his ability as a scientist and a manager that were very complimentary. In a subsequent conversation with Rhodes, however, he abruptly put his index finger and thumb together so that no light could be seen between them and said "Norman could hold a metal coupon between his finger and thumb and in a matter of seconds tell you within a fraction of a millimeter how thick that coupon was." I thought for a second and said "Sounds like he was an engineer's engineer but I don't know what practical use that would be." In response, Jack said that he didn't either but Norman was one of the most practical people he had ever worked with. His book, *Fire Behavior and Sprinklers* reflects that; it is a practical and wise summation of the development of sprinkler technology through the first half of the 20th century that we would all be wise to revisit on a regular basis.

Norman J. Thompson was born in March 1894. He was a graduate of the Massachusetts Institute of Technology Cambridge, MA USA. Following graduation, he worked for the automotive and steel industries as a metallurgist and joined FM in 1924. As a research engineer there, he was instrumental in the development of many techniques and devices used in fire prevention and protection. His most notable contribution was the design and development of the spray sprinkler, now known as the standard sprinkler. In 1941, Mr Thompson became a founder of FMRC. Mr Thompson retired from FM in 1959 and died in 1971 at the age of 77.