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FIRE TESTS TO COMPARE SPRINKLER DEMANDS OF WET-PIPE AND DRY-PIPE SYSTEMS

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ABSTRACT

Scale-model and full-size fire tests show that demand on dry-pipe sprinkler systems are greater than those on wet-pipe systems. Given equal freeburn times on selected commodities, dry-pipe systems require more sprinkler operations than do wet-pipe systems in direct ratio to water-delay times when the water-delay time is greater than 52 seconds. With water-delay times under 52 seconds, the total sprinkler demands of wet-pipe and dry-pipe systems are essentially the same.

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Background

In Factory Mutual insured plants, about one system in four is a dry-pipe system. It has been speculated that the sprinkler demands for dry-pipe systems are larger than for wet-pipe systems. The cause is assumed to be the delay of water arrival to operating sprinklers in a dry-pipe system. Research to prove or disprove this assumption has been in progress at Factory Mutual Research Corporation for years. First, a method had to be developed to predict total time delay between opening of the first sprinkler and water arrival at open heads. Given sprinkler operation sequence and dry-pipe system parameters, the delay time could be predicted with acceptable accuracy. A series of model-scale experiments was conducted to investigate the effect of water delay on final sprinkler demand. It was possible, based on the results of this experimental work, to reach conclusions on the sprinkler demands of wetpipe and dry-pipe systems. A series of full-scale fire tests was then conducted to compare the sprinkler demands of wet-pipe and dry-pipe systems. The objective of these tests was to verify model study findings. Another objective was to obtain data for our bank of knowledge relating to dry-pipe versus wet-pipe sprinkler demands. It was anticipated that successful achievement of the program objectives would result in findings that could be applied to dry-pipe systems in the field.

Introduction

Figure 1 illustrates a sprinkler system which includes a water supply connected to a network of overhead piping to which automatic sprinklers are connected in a systematic pattern. The system includes a controlling valve and a device for actuating an alarm when the system is in operation. The sprinklers would be activated by heat from the fire and discharge water over the fire area. For a system of about 2 m^3 capacity, the riser and feed main could be positioned as shown to maintain a relatively uniform sprinkler water discharge. This arrangement is known as a center-central fed system.

In a wet-pipe system, the riser would not contain a dry-pipe valve, but would include an alarm check valve. The piping system would be full of water, and upon operation of the first sprinkler in the vicinity of the fire, water would immediately discharge where it can protect both the structure and the contents.

In a dry-pipe system, a dry-pipe valve would be in the riser, as shown. All of the piping above the dry-pipe

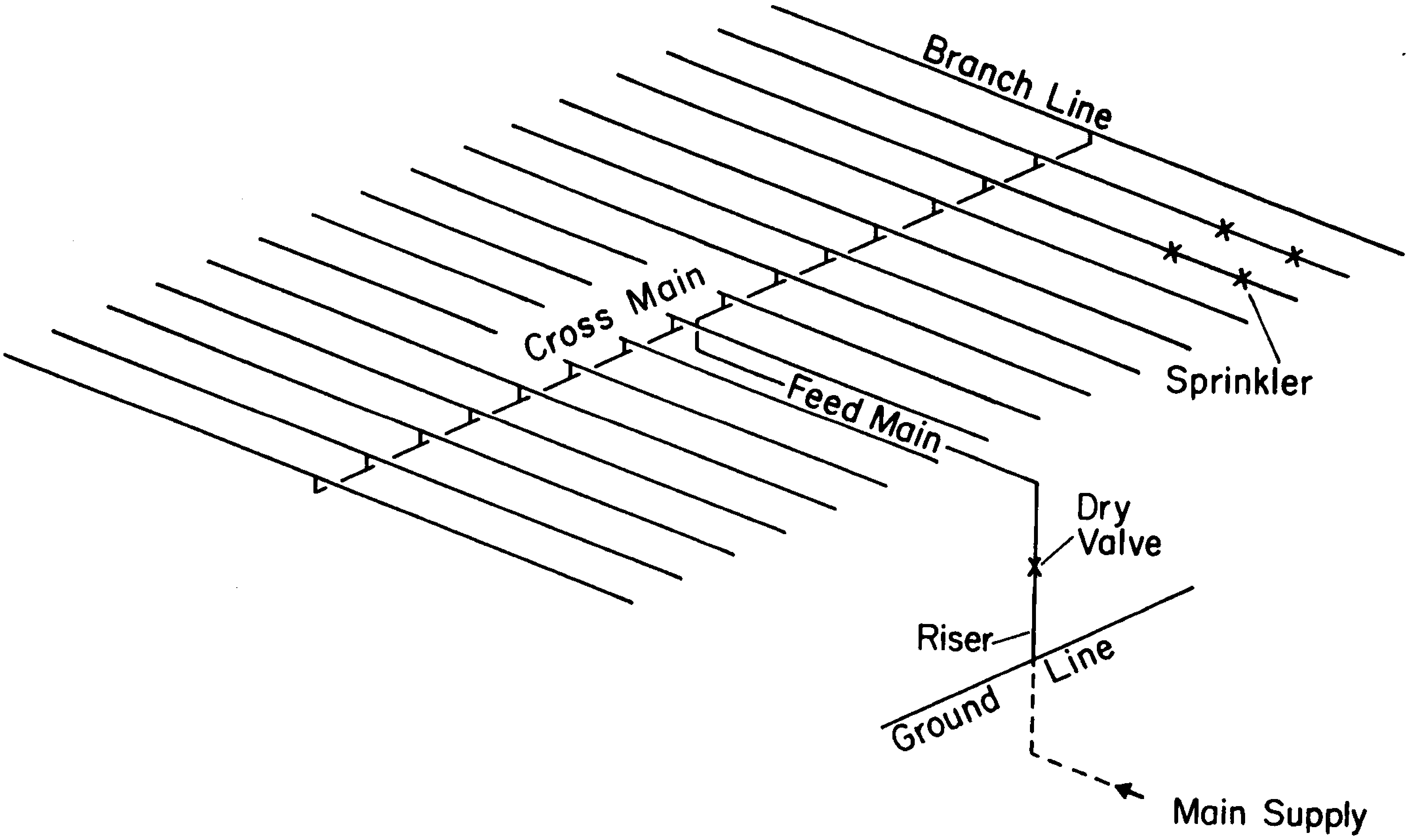

Figure 1. A typical sprinkler system.

valve contains air under pressure. Whenever the first sprinkler operates, the air would be released. Then, the drypipe valve would open. Water would flow up the riser and through the feed main, cross main, and branch lines and out opened sprinklers to protect both the structure and contents. Dry-pipe systems are somewhat less efficient than wet-pipe systems because of the delay in water arrival on the fire after sprinkler heads have fused. The total time elapsed between activation of the first sprinkler and the time that design water flow density is reached at fused sprinklers can be calculated by use of techniques developed during the previously conducted model experiments. In order to make this calculation, it is necessary that drypipe system parameters such as pipe schedule, initial water pressure and initial water pressure and initial air pressure as well as sprinkler opening sequence be known.

Model Experiments

Model fires were conducted using a one-twelfth scale model of the Factory Mutual fire test building in Rhode Island. All geometric features of importance were reproduced. The ground plan around the building was simulated by "air guide aprons" installed in front of all doors. Spray nozzles were developed that simulated sprays of full-scale sprinklers. The model sprinklers were zoned in approximate circles around the ignition point. Each zone was activated by a simulated sprinkler link on the corresponding circle by a temperature controller and solenoid valve in the water line.

The model fires were conducted at constant sprinkler water flow density. The water delay after first sprinkler activation was controlled systematically, and sprinkler operation sequence, including the final number, was observed. Three important parameters were identified. The first is fire size defined as the total wet-pipe mode sprinkler operations, with no water delay. That is, in a wet-pipe system the water delay would be zero seconds. Water would discharge immediately upon operation of the first sprinkler. Then the automatic sprinkler operations would increase with time to the total wet-pipe number.

Another parameter is water delay time, which is defined as the interval between first sprinkler operation and the time that system design pressure is reached. In other words, after first sprinkler operation in a dry-pipe system, it would take a finite time delay for the dry-pipe valve to trip. Then, an additional delay would occur as water travelled through sprinkler piping and open heads to reach design water flow density at operating sprinklers.

The third parameter is freeburn time which is determined in a freeburn test with water held back for a sufficiently long period of time. That is, with a dry-pipe system, sprinkler operations occur even though water has not yet reached fusing sprinklers. The freeburn time is defined as the interval between the first sprinkler and that number of sprinkler operations which equals the wet-pipe demand.

In a conceptual representation (Figure 2) the total number of sprinkler operations, is shown on the vertical axis, while the time interval after first sprinkler operation is shown on the horizontal axis. In the wet-pipe mode, as shown by the dashed curve, the cumulative number of sprinkler operations have been plotted versus elapsed time after first sprinkler operation. Water is assumed to discharge immediately upon operation of the first sprinkler, therefore, water delay time, is zero seconds. The automatic sprinkler operations are seen to increase with time after first sprinkler operation to the final number shown on the vertical axis. Also, in the freeburn mode, an operable sprinkler system is present. However in this case, the water has been drained from the system. Therefore, as sprinklers fuse, water does not flow, and

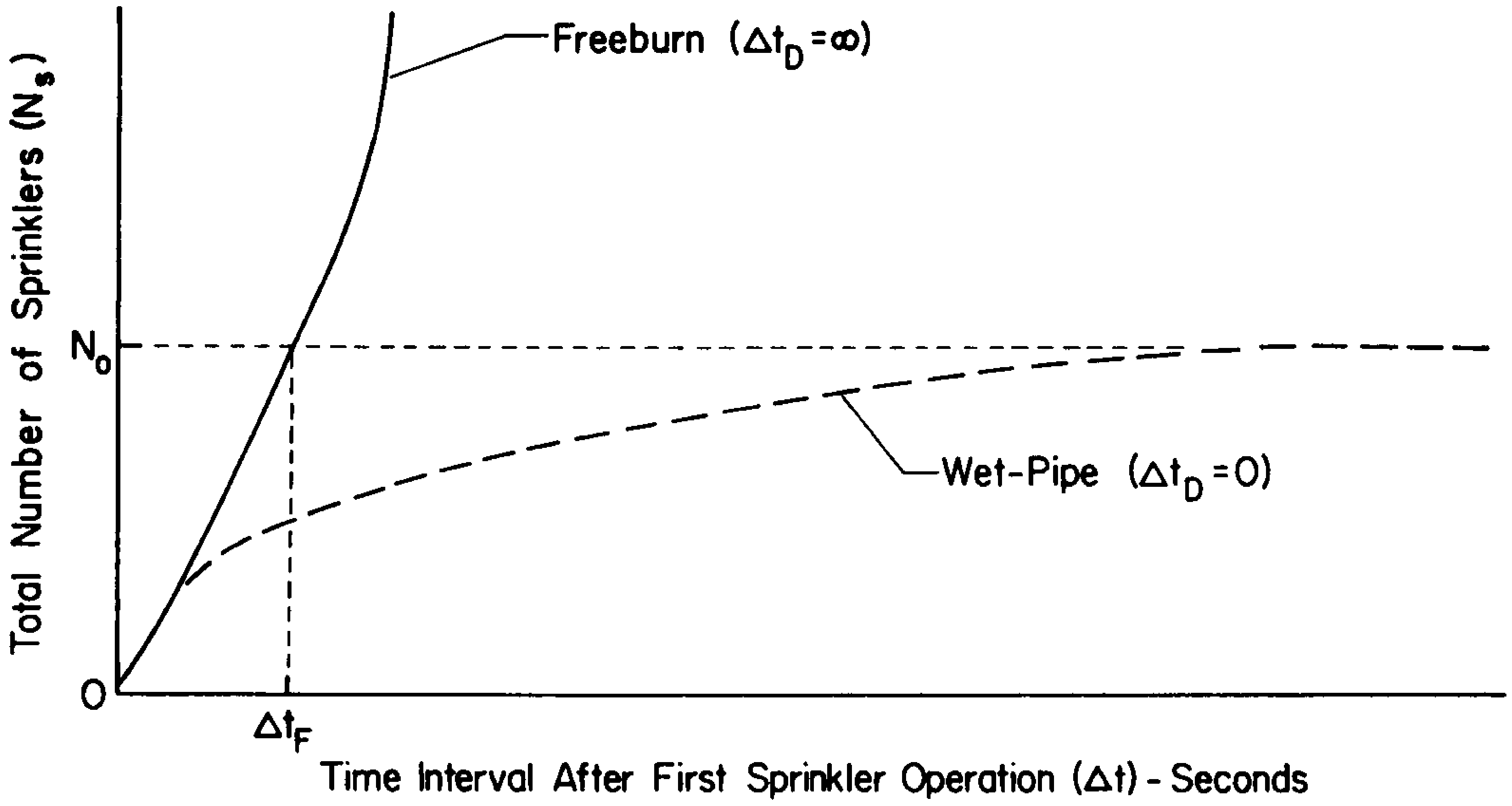

Figure 2. N_0 = Fire size, total wet-pipe operations.

Δt_D = water delay time. Interval between first operation and the time system designed pressure is reached.

Δt_F = Freeburn time.

we have a simulated dry-pipe system. If water is withheld for a long delay time, sprinkler operation versus time after first sprinkler would occur as shown by the solid curve. The freeburn time, Δt_F, shown on the horizontal axis, corresponds to the time when the wet-pipe number of sprinklers have operated.

An important result of the model experiments was this: as long as the water delay time of a dry-pipe system is less than, or equal to, freeburn time the total number of dry-pipe sprinkler operations will equal the wet-pipe number of sprinklers. In other words, as long as the water reaches full pressure at open heads at time delays smaller than Δt_F, the final number of dry-pipe sprinklers will eventually level off to the number of sprinklers which activate in a wetpipe system protecting the same commodity. Clearly, if water delay time is greater than freeburn time, a larger number of sprinklers will operate in a drypipe system than in a wet-pipe system, since sprinkler operations in excess of the wet-pipe number would already have occurred during the freeburn interval preceding first water arrival at fused sprinklers. Consequently, to assess the sprinkler demands of wet-pipe and drypipe systems, it is necessary to compare the freeburn time, with the water delay time, of dry-pipe systems.

Full-Scale Fire Tests

A series of full-scale fire tests was conducted with the objective of verifying the model study findings. Another objective was to obtain data for our bank of knowledge relating to dry-pipe versus wet-pipe sprinkler demands. We selected full-scale commodity and storage arrangements that previously had been tested in the wet-pipe mode at our Test Center. These test configurations were considered to be representative of those found in the field. The selected test configurations were arbitrarily grouped according to fire size which has been defined as the total wet-pipe mode sprinkler operations. A fire that caused 40 to 50 sprinkler operations in a wet-pipe system was defined as a large fire size. In an intermediate fire size, from 20 to 30 sprinkler operations would occur. A small fire size would have a wet-pipe demand of about 5 sprinkler operations. Then, with wet-pipe sprinkler demand already available, simulated dry-pipe system fire tests were conducted with water delay time as the controlled variable.

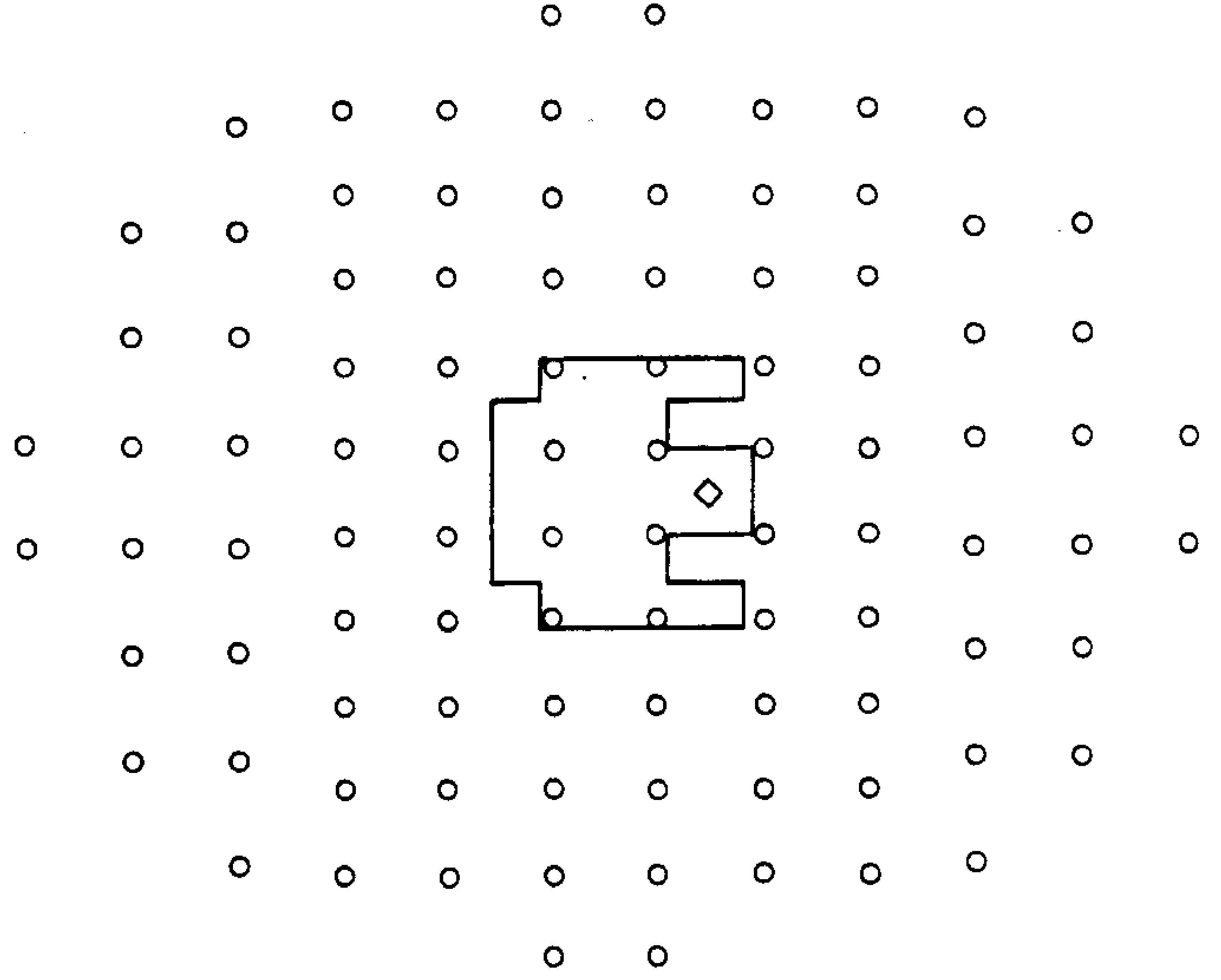

Figure 3. Fuel and sprinkler arrangement for fire test.

Six different commodity and storage arrangements were tested, of which the one shown in Figure 3 is representative. Here, is an intermediate fire size stored plastics commodity consisting of palletized rigid polystyrene 1/2 liter containers. Each container was individually compartmented within cardboard cartons. The Fuel array was about 8 m wide by 8 m long by 5 m high and was located on a 1.5 m platform to give a clearance of 3 m from the top of the pile to the ceiling. Sprinkler protection was provided by 138°C rated, 1.3 cm orifice diameter automatic sprinklers on 2.4 m x 3 m spacing. The water flow density was 24.5 mm/min. The fuel boundary is shown by a solid line. Fire ignition took place at the location of the diamond. Automatic sprinkler locations are shown as circles. For the wet-pipe mode, water on demand was provided as 24 sprinklers operated. In a simulated dry-pipe mode, water was intentionally withheld from fusing sprinklers for a pre-selected time interval after first sprinkler operation. Then, the fire developed in a freeburning manner until water was provided to the fusing automatic sprinklers.

Fire development during a full-scale test with this rigid polystyrene commodity shows how water delay time affects total sprinkler demand. For this test, the water delay time was 79 sec. After fire ignition, the fire travelled upward through the ignition flue to form a fire plume that impinged onto the ceiling directly over the ignition point. A few seconds later, the gas temperature had increased to about 900°C, and the gas velocity over ignition was about 9 m/sec. At about the same time, first sprinkler operation occurred. Within 22 sec of the first sprinkler, the temperature over ignition reached 1150°C as the gas velocity increased to 12 m/sec. Then, by 52 seconds after first sprinkler operation, 25 sprinklers had operated. Control valves were actuated 6 seconds later to permit water flow toward operating sprinklers. It should be noted that a freeburn condition still existed because water had not yet reached the sprinklers. However, during the 8 seconds it took water to flow through cross-mains and branch lines, toward fusing sprinklers, additional operations occurred for a total of 43 at first water arrival. At about the same time, almost the entire top of the fuel array was involved in the fire. Then 13 seconds later, system design pressure was reached, and the total demand was 58 sprinklers. There was little change in fire involvement and the fire was then brought quickly under control.

Figure 4 is a plot of sprinkler operations versus time after first sprinkler operation for several fire tests with the rigid polystyrene commodity. The solid curve is for the fire test just described which had a water delay time of 79 seconds. At 79 seconds after first sprinkler operation, system design pressure was reached and the 58th and final sprinkler operation occurred. The lowest dashed curve data are for a wet-pipe system where water delay time is zero seconds. In this case, water was discharged immediately after the first sprinkler operated. As shown, the total demand is 24 sprinklers. To determine the freeburn time, enter the vertical axis with the 24 operations for a wet-pipe system. Intersect the solid curve, and read 52 seconds on the horizontal axis. Therefore, the freeburn time is 52 seconds. Since that is the freeburn interval between the first and the 24th sprinkler operations obtained for the wet-pipe system, sprinkler operation data for fire tests with water delay times of 34 seconds and 51 seconds are shown by the two additional dashed curves on the graph. The sprinkler operations follow the freeburn curve until water is supplied to fused sprinklers. The total demand for each of these two tests is within 2 sprinklers of the 24 wet-pipe operations. It is apparent from this graph that with water delay times equal to or less than 52 seconds, the dry-pipe and wet-pipe system sprinkler demands are essentially equal.

The sprinkler operation sequence, during the freeburn portion of the test, can also be used to calculate water delay time. The selected pipe schedule system; was center-central fed with about a 2 m^3 capacity; included new pipe and associated hardware; and, had a realistic water supply and initial air pressure. The dry-pipe valve differential was specified as 6:1, and accelerators, exhausters, and preaction devices were not included. The calculated water delay time is 40 seconds. This is 12 seconds less than the freeburn time of 52 seconds to operate 24 sprinklers. That is, the calculated water delay time is less than the freeburn time as determined from a fire test with the rigid polystyrene commodity. Consequently, it would be expected, for this particular dry-pipe system, that the dry-pipe and wet-pipe sprinkler demands would be essentially equal.

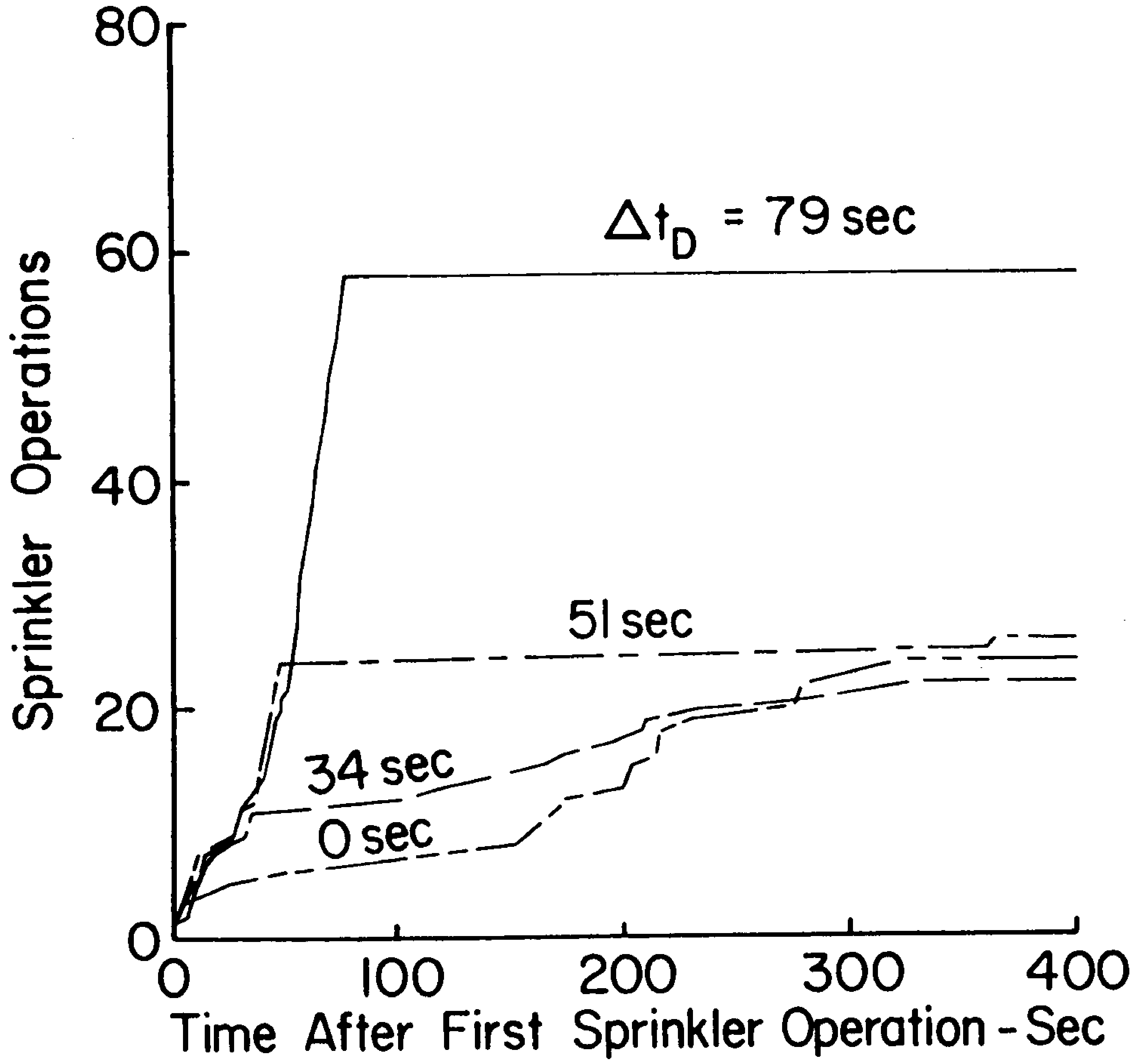

Figure 4. Sprinkler operations vs time.

Comparison of Sprinkler Demands For Wet-Pipe and Dry-Pipe Systems

We know from full-scale test results that if water is withheld from operating sprinklers for a long delay time, the freeburn sprinkler operations increase rapidly. In the wet-pipe mode, where water delay time is zero seconds, the cumulative sprinkler operations would increase much less rapidly and the total sprinkler demand would be lower. It was found that if the dry-pipe system water delay time is less than, or equal to, the freeburn time of 52 sec, the total sprinkler demand of the dry-pipe system would be essentially the same as for a wet-pipe system. For a particular dry-pipe system, with a water delay time of 40 seconds, the sprinkler operations with time would follow the freeburn curve until water arrival at fusing sprinklers. Then, the cumulative sprinkler operations would increase along some path to eventually the same level as those for a wet-pipe system. With water delay time greater than the 52 seconds freeburn time, it was found that dry-pipe sprinkler demand would be greater than the wet-pipe demand. In a dry-pipe system that has a water delay time of 60 seconds, the cumulative sprinkler operations versus time could follow the freeburn curve until the time that design pressure was reached to produce the design 24.5 mm/min water flow density at opened sprinklers. At about the same time, final sprinkler operation would occur to define the total sprinkler demand as shown in Figure 5. Since final sprinkler operation occurred at a time later than that for the 24th freeburn operation, it is clear that the

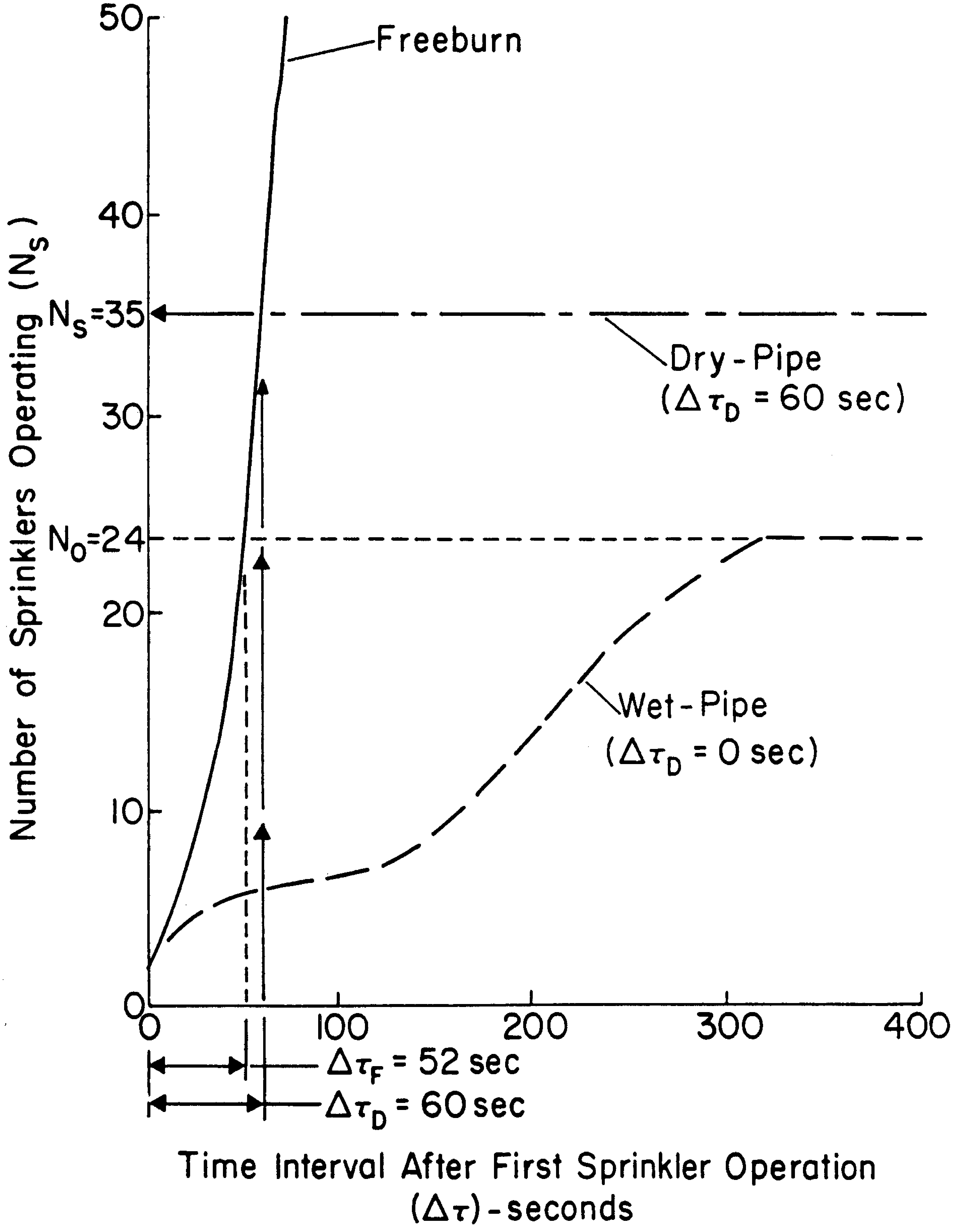

Figure 5. Comparison of sprinkler demand in wet-pipe and dry-pipe systems.

COMPARISON OF SPRINKLER DEMANDS FOR WET- AND DRY-PIPE SYSTEMS

Fire Size	Commodity Description	Δt_D (sec)	Δt_F (sec)	N_o	N_s	$\frac{\Delta t_D}{\Delta t_F}$	$\frac{N_s}{N_o}$
Intermediate	Stored Plastics Polystyrene 16 oz Tubs in Compartmented Cardboard Cartons	0	52	24	24	0	1
		34	↓	↓	22	0.65	0.92
		51			26	0.98	1.08
		79			58	1.52	2.42

Table 1. Sprinkler demands for wet-pipe and dry-pipe systems.

dry-pipe sprinkler demand would be greater than the wet-pipe demand. Table 1 tabulates the results for the rigid polystyrene commodity tests. Total sprinkler demand for a given delay time is listed. Also included are freeburn time and wet-pipe sprinkler demand. As shown, the water delay time has been divided by freeburn time to form a delay time ratio. Also the total sprinkler demand has been divided by the wet-pipe demand to form a sprinkler demand ratio. For wet-pipe systems, it is obvious that the sprinkler demand ratio is unity while the delay time ratio is zero. As long as the delay time ratio is smaller than one, the sprinkler demand ratio remains near unity. On the other hand, when the delay time ratio is greater than one, the sprinkler demand ratio is greater than unity. It is clear from the table that, as long as the delay time ratio is less than, or equal to, unity, the total sprinkler demand of wet-pipe and dry-pipe systems are essentially the same. If the delay time ratio is greater than unity, the total sprinkler demand for a dry-pipe system is greater than for a wet-pipe system. Similar results were obtained for the other commodities tested. The other commodities included cardboard cartons with sheet metal liners and foamed polystyrene.

Conclusions

These findings are based upon use of non-decaying water densities and a particular pipe schedule system with specific commodity and storage arrangements. One of the two controlling variables is the freeburn time, which is the time interval between the first sprinkler operation and that number of sprinkler operations which equals the wet-pipe demand. The other is the water delay time which is the interval between first sprinkler operation and the time that system design pressure is reached.

There are two important findings. The first finding is that whenever water delay time is less than, or equal to, freeburn time, the dry-pipe system sprinkler demand is essentially the same as for a wet-pipe system. In practice, this is likely to be the case for large fires with well maintained pipe schedule sprinkler systems. The second finding is that whenever the water delay time is greater than the freeburn time, the dry-pipe system sprinkler demand is greater than the demand for a wet-pipe system.

This study relates only to the effects of delay time on the sprinkler demand. Other aspects of dry-pipe sprinkler systems, such as formation of ice plugs or scale deposits, could also affect total sprinkler demand. One of the significant accomplishments in this work was the successful completion of model scale fire tests that led to findings regarding dry-pipe versus wet-pipe sprinkler demands. A second accomplishment was the successful verification of model study findings through full-scale fire tests. It has also been possible to develop a methodology for determining the total sprinkler demand of dry-pipe systems. To implement the methodology we need: 1) the total number of wet-pipe sprinkler operations; 2) the freeburn sprinkler operation curve; and 3) transient hydraulic calcualtions.

PUBLISHER'S NOTES

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