EVALUATION OF SPRINKLER ACTIVATION PREDICTION METHODS

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SUMMARY

The objective of this study was to evaluate the ability of sprinkler activation models to predict activation time. Large scale compartment fire tests were used to obtain activation times for four different types of sprinklers. The tests were conducted in an 18.9 m by 9.1 m by 2.35 m high compartment using floor based, gas burner fires with constant heat release rates of 115, 155, 215, 290 and 520 kW. Non-dimensional sprinkler radial positions, r/H, of 0.67 and 1.3 were evaluated. In addition to sprinkler activation times, ceiling jet temperature, velocity and radiation measurements were made. The study included: 1) a review of public domain, personal-computer based, single-compartment thermal-detector activation models, 2) an analysis of predicted vs. experimental sprinkler activation times and 3) a method to determine the applicability of current sprinkler activation models.

INTRODUCTION

Computer models have become primary tools enabling fire protection engineers to analyze fire protection problems. Thermal or sprinkler activation models are being used by fire protection engineers in the design and evaluation of fire suppression systems. Therefore it is important to know the accuracy and the limitations of the current sprinkler activation models. This study was conducted at the Building and Fire Research Laboratory of the National Institutes of Standards and Technology under the sponsorship of the General Services Administration. In this study, sprinkler activation times were compared with predictions from three models; DETACT-QS[1], LAVENT[2], and FPEtool[3]. These models were chosen because they are public domain, personal-computer based models which represent a cross section of available sprinkler activation algorithms .

SPRINKLER ACTIVATION MODELS

DETACT-QS, LAVENT Version 1.1 and FPEtool Fire Simulator Version 3.00 were chosen for comparison with the experimental results. These models utilize only convective heat transfer from the ceiling jet to the sprinkler's thermal element. Heat transfer to or from the thermal element due to conduction or radiation heat transfer mechanisms are not considered. The primary difference between the models is how they predict the ceiling jet temperatures.

DETACT-QS is based on Alpert's[4] empirical ceiling jet correlations. These correlations assume that the thermal element of the sprinkler is located at the maximum temperature and velocity position beneath a smooth, unconfined ceiling. Alpert developed steady-state correlations for temperature and velocity of the ceiling jet based on the total heat release rate of the fire, ceiling height and radial distance of the detector from the fire plume axis. These equations are also the basis for the FPEtool activation algorithm.

LAVENT was developed to predict the activation of sprinklers and thermally sensitive link-actuated ceiling vents in compartment fires. LAVENT takes into account the effect of the upper, hot gas layer on the ceiling jet, as well as heat loss to the ceiling and the distance between the ceiling and the sprinkler link.

In the Fire Simulator sub-model of FPEtool, the sprinkler activation algorithm considers the effect of the hot gas layer on the ceiling jet and the heat loss to the walls and the ceiling, but it does not take into account the distance of the sprinkler below the ceiling. It assumes that the thermal element is positioned at the maximum temperature and velocity of the ceiling jet beneath the ceiling in the same manner as DETACT-QS.

EXPERIMENTAL APPROACH

Large-scale compartment fire tests were used to obtain activation times for four different types of pendent sprinklers; a quick-response bulb, a quick-response link, a standard- response bulb and a standard-response link sprinkler as shown in table 1. The tests were conducted in a space 18.9 m by 9.1 m with a ceiling height of 2.35 m (figure 1). During the experiments the room was closed, but not sealed, and no mechanical ventilation was operating. This provided a quiescent test environment. The ceiling of the compartment was composed of 12 mm thick gypsum board. The area of the ceiling above the fire and continuing past the sprinkler measurement locations was covered with 12 mm thick calcium silicate board in addition to the gypsum board. The walls of the compartment were composed of concrete block.

The fire source for all of the tests was a gaseous propane diffusion flame. The heat release rates of the steady-state fires used in the study were 115 kW, 155 kW, 215 kW, and 290 kW at a radial distance to ceiling height above the fuel (r/H) ratio of 0.67 and 290 kW and 520 kW at an r/H ratio of 1.3. In addition to sprinkler activation times, ceiling jet temperature, velocity and radiation measurements were made [5]. Three replicate tests were conducted for each scenario. The data, from the three tests, was then averaged and the 95% confidence limits were calculated. Assuming the data has a normal distribution, the region defined by the 95% confidence limits is such that any arbitrarily chosen single result has a 95% chance of being included in that region. In this study, reasonable agreement was defined as being within the 95% confidence limits of the data.

RESULTS

In figures 2 through 9, predictions from the sprinkler activation models were compared with the experimental results and the 95% confidence limits. The graphs show that DETACT-QS always provides conservative results, i.e. longer predicted activation times, compared to the experimental data. In general, LAVENT and FPEtool were found to provide reasonable agreement or conservative activation times compared to the test results, but when DETACT-QS predicted no activation, in most cases LAVENT and FPEtool under-predicted the sprinkler activation times.

For quick response sprinklers, there are two clear cases where the models fail to provide acceptable agreement with the experimental data – the 290 kW, r/H = 1.3 case and the 115 kW, r/H = 0.67 case. In these cases the measured ceiling jet temperature was very close to the sprinkler activation temperature. LAVENT and FPEtool under-predict the activation time because the ceiling jet temperature was over-predicted. When the ceiling jet temperature is very close to the sprinkler's activation temperature, the sprinkler's thermal element temperature approaches the activation temperature asymptotically. In the asymptotic region, the predicted activation time is extremely sensitive to the predicted ceiling jet temperature.

Figure 10 shows the predicted temperature rise of the thermal response model to three different, steady-state ceiling jet temperatures. Given a sprinkler with an activation temperature of 74 °C, a time constant or τ of 23 seconds and an ambient temperature of 25 °C, the sprinkler's theoretical response to three different steady state ceiling jet temperatures is shown. The 135 °C gas temperature is representative of the temperature used in the plunge test[6]. Notice that the sprinkler reaches activation during a period of rapid temperature increase. If the sprinkler's environment changed, causing a slightly lower (<5 °C difference) ambient temperature or lower ceiling jet gas temperature the effect on the time of sprinkler activation would be minimal (< 2 s difference). The situation is similar for the 110 °C curve which is representative of the ceiling jet temperature in the first 30 seconds of the 290 kW, 1.5 m case. However, the activation time of the same sprinkler exposed to a 75 °C gas temperature which is representative of the average ceiling jet temperature for the 115 kW case, would change significantly if the temperature of the ceiling jet was reduced by 1 °C or no activation at all if the ceiling jet temperature was reduced by 2 °C.

In all of the cases where DETACT-QS predicted no activation, LAVENT significantly under-predicted the activation times. When DETACT-QS predicted no activation, FPEtool provided inconsistant prediction of activation times, which is a non-conservative result with respect to life safety analysis. This study suggests that DETACT-QS can be used as a screening test to determine if the design fire used in the analysis is in a range where LAVENT and FPEtool can be used to provide reasonable or conservative predictions.

DISCUSSION ON SPRINKLER ACTIVATION MODEL USAGE

The results of this study suggest the following when using one of these sprinkler activation models. After the design fire, the sprinkler's thermal response characteristics (activation temperature and RTI) and the r/H ratio are chosen, check the maximum temperature increase provided by DETACT-QS for the case under investigation. If the temperature increase is equal to or less than the increase required to activate the sprinkler, then based on the results of this limited study, an accurate prediction cannot be made with any of the three models. However, if DETACT-QS provides a ceiling jet temperature increase greater than that needed to activate the sprinkler head, then the predicted activation time from any of the three sprinkler activation models can be used, provided that the DETACT-QS predicted sprinkler activation is not occurring in the asymptotic response region. Because of the limited experimental data, this recommendation may not hold for situations that are greatly different from the geometry tested, in particular high bay spaces and/or in areas where the fire source maybe close to walls or corners.

CONCLUSIONS

The ability of three thermal activation models to predict sprinkler activation times was checked against activation times measured in large-scale compartment fire tests. None of the models provided accurate predictions for all of the cases. Prediction of the ceiling jet conditions were compared to the measured conditions to determine the cause of the cases with poor agreement between the predictions and the actual activation time. Analysis of the data revealed that sprinkler response is difficult to predict accurately when the sprinkler is exposed to ceiling jet temperatures near the sprinkler's activation temperature. A procedure is described which uses DETACT-QS to determine if the models, which include secondary effects, are applicable for the design fire under consideration.

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Table 1 - Sprinkler Types Used in Full Scale Activation Testing

Sprinkler Type	Activation Temperature (°C)	Response Time Index ($m^{1/2}$ $s^{1/2}$)
Quick Response Bulb	68	42
Quick Response Link	74	34
Standard Response Bulb	68	235
Standard Response Link	74	130

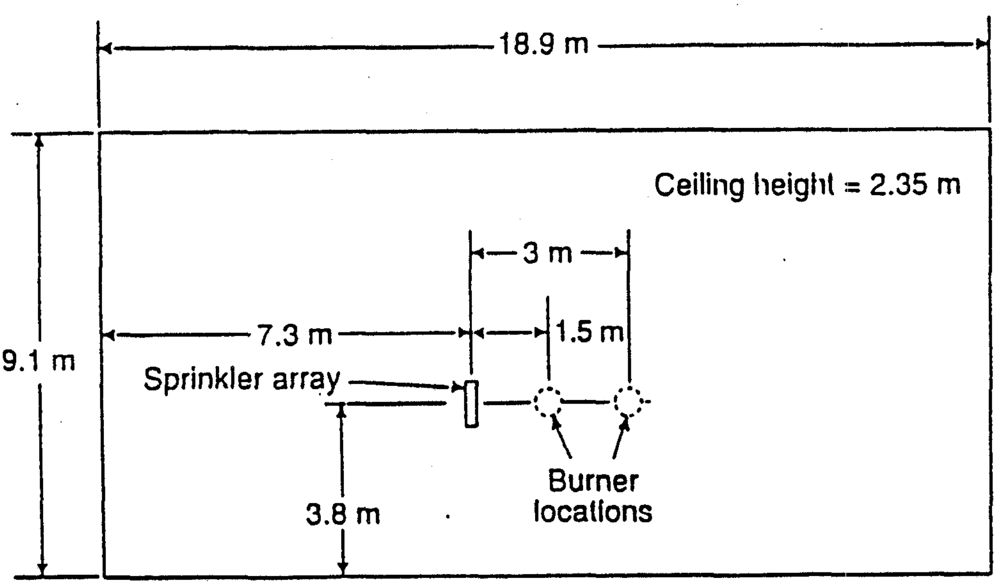

Figure 1 - Schematic of sprinkler activation test area, plan view.

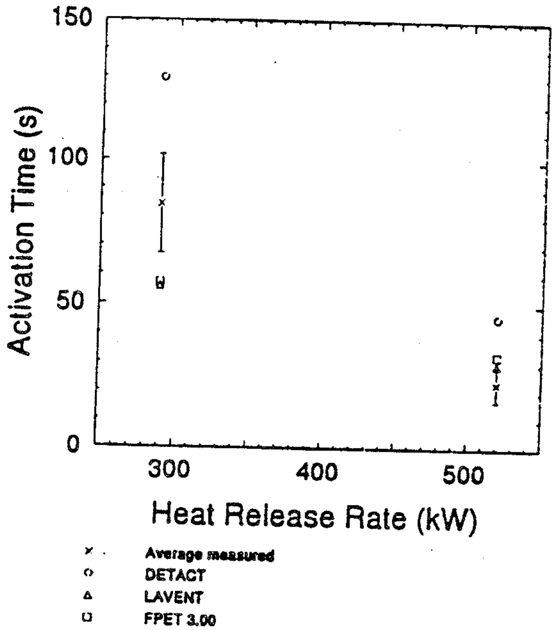

Figure 2 - Measured and predicted activation times at $r/_H$ = 1.3, QR bulb

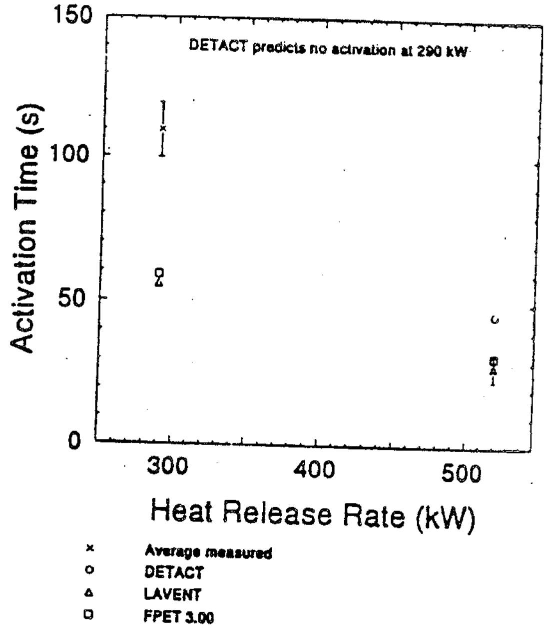

Figure 3 - Measured and predicted activation times at $r/_H$ = 1.3, QR link

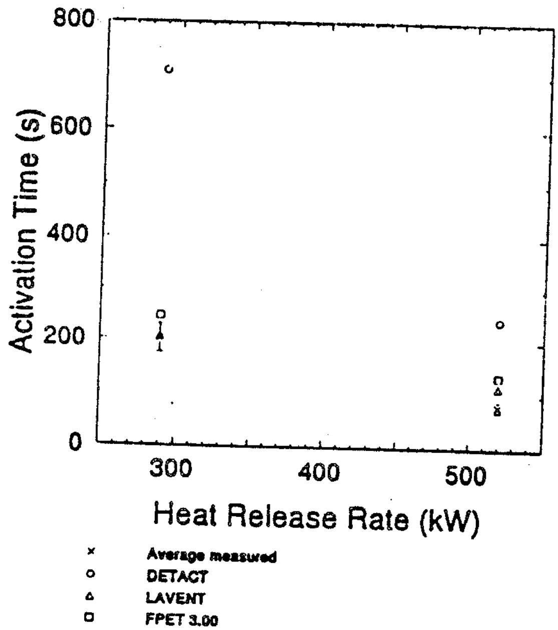

Figure 4 - Measured and predicted activation times at $r/_H$ = 1.3, SS bulb

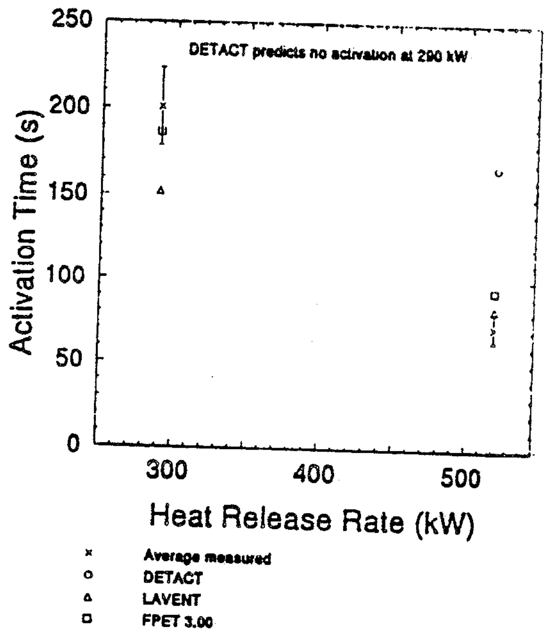

Figure 5 - Measured and predicted activation times at $r/_H$ = 1.3, SS link

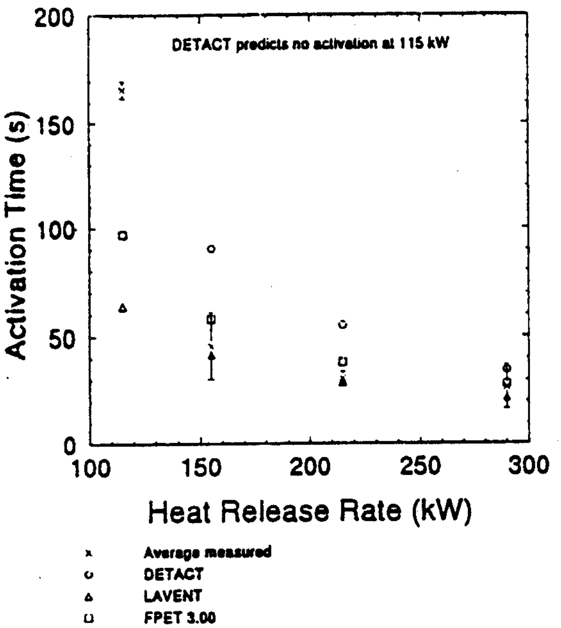

Figure 6 - Measured and predicted activation times at $^{r}/_{H}$ = 0.67, QR bulb

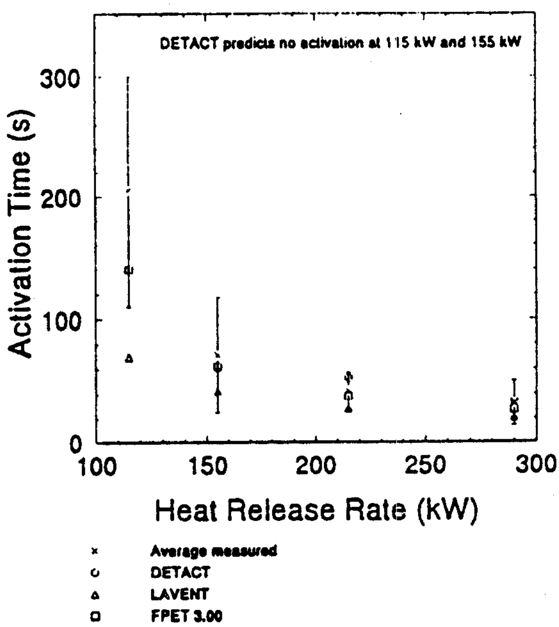

Figure 7 - Measured and predicted activation times at $^{r}/_{H}$ = 0.67, QR link

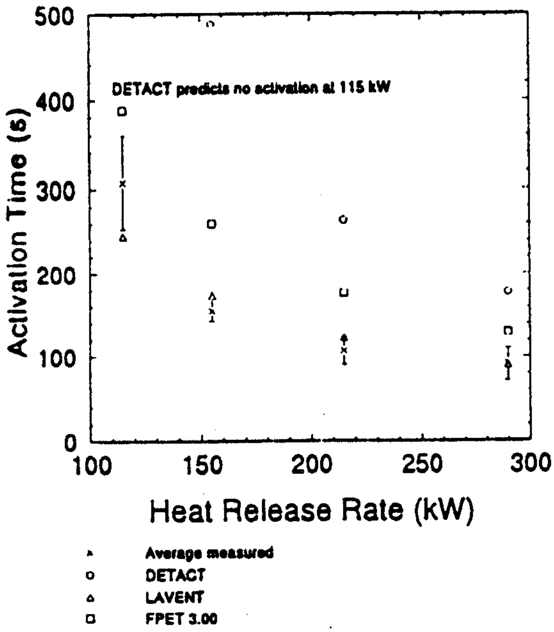

Figure 8 - Measured and predicted activation times at $^{r}/_{H}$ = 0.67, SS bulb

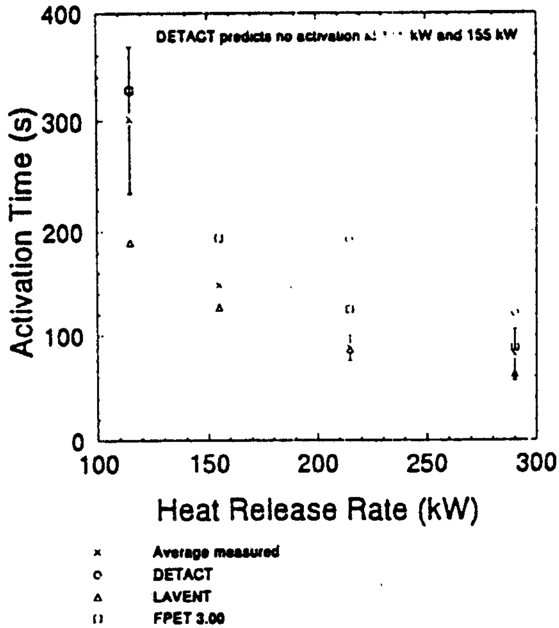

Figure 9 - Measured and predicted activation times at $^{r}/_{H}$ = 0.67, SS link

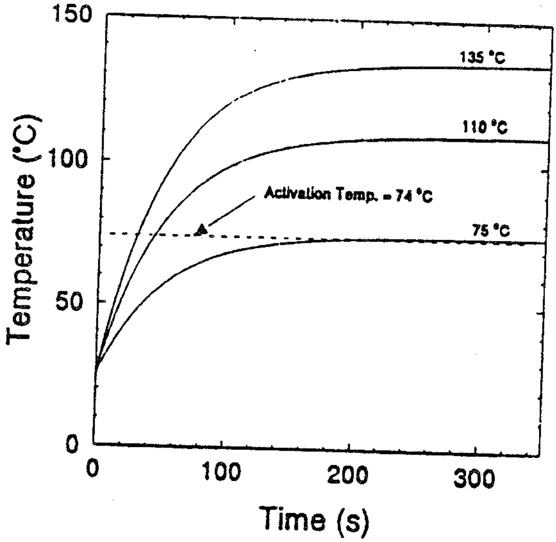

Figure 10 - Predicted response sensitivity to gas temperature