Coupled Automatic and Manual Fire Protection for Top-Loading Automatic Storage and Retrieval Systems

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Abstract

Top-loading automatic storage and retrieval systems (TL-ASRS) create a very challenging condition for traditional fire protection systems. Multiple robots powered by on board batteries travel simultaneously along rails above tightly spaced stacks of plastic containers, resulting in extremely dense combustible storage without aisle spaces or other means to access the storage area. Large-scale fire tests have shown that final extinguishment can be achieved through the combination of automatic sprinklers at the ceiling coupled with manual firefighting strategies, specifically remotely operated fire monitor nozzles. In addition, final extinguishment may be assisted through installation considerations, such as access walkways to improve fire service access, and operational considerations, such as robots vacating the fire area.

Keywords: Automated storage, robotic storage, fire tests, fire protection, final extinguishment

Extended Abstract

Top-loading automatic storage and retrieval systems (TL-ASRS) are a relatively new logistical approach to warehouse storage and distribution, operating on densely packed storage space. Remotely operated robots traverse across the top of the grid and are used to either remove containers from the storage grid for picking operations or to return containers to their designated storage location.

Testing of traditional fire protection systems, comprised of ceiling-level sprinklers, has shown promising results at suppressing the initial fire [1, 2] but also identified a key challenge. Since the early 2010's, different approaches have been investigated, including sprinkler systems designed to control the fire, suppress the fire, or specialty systems incorporating fire-fighting foam additives [1, 2]. Unfortunately, none of these approaches accomplished the most challenging task i.e., final extinguishment without the need for manual fire service intervention.

This paper summarizes five large-scale fire tests that were conducted in 2019 to evaluate the effectiveness of combining automatic sprinkler protection and manually operated fire monitors at achieving final extinguishment of a fire in a commercial TL-ASRS. Installation and operational considerations were also addressed, including vertical barriers to prevent fire spread, obstructions created by robots in the fire area, impact of openings within the storage array, and overhaul after a fire event.

The TL-ASRS used in this testing consisted of an open metal grid structure that was 5.5 m (18 ft) tall and was supported by lightweight aluminum metal columns located at the corners of each grid opening. Under each grid opening was an ~ 5.3 m (17.5 ft) tall stack consisting of 16 containers, each with dimensions of 449 × 649 × 330 mm tall (17.7 × 25.6 × 13 in). The storage containers were open-top with solid walls and bottom and were made from high-density polyethylene (HDPE) plastic. All containers were filled with a cartoned unexpanded plastic product (plastic cups in a corrugated board box) to simulate normal storage conditions.

Ignition occurred at the bottom of the storage array, offset one grid spot from the center of the array, and the ignition stack was only partially filled to four containers high. A mock robot was positioned directly above ignition on the top grid to represent a realistic use condition where a robot becomes disabled.

Automatic ceiling-level sprinkler protection was provided in all tests, using pendent sprinklers with a 68 °C (155 °F) temperature rating and a nominal response time index (RTI) of 27.6 $m^{1/2}s^{1/2}$ (50 $ft^{1/2}s^{1/2}$). Tests 1 - 4 evaluated sprinklers with a K-Factor of 200 $l/min/bar^{1/2}$ (14 $gpm/psi^{1/2}$). Tests 1, 2 and 4 were conducted with 12.2 m (40 ft) ceiling height and had the protection set at 49 mm/min (1.2 gpm/ft^2) density. Test 3 was conducted with a 7.6 m (25 ft) ceiling height and was run with a 41 mm/min (1.0 gpm/ft^2) density. For Test 5 the discharge density for a ceiling height of 12.2 m (40 ft) was doubled to 98 mm/min (2.4 gpm/ft^2), which required larger orifice sprinklers with a K-Factor of 360 l/min/bar½ (25.2 $gpm/psi^{1/2}$). In each case the sprinkler protection alone was not able to achieve final extinguishment, even using prolonged water durations of 90 minutes that exceeded typical building requirements [3, 4].

Final extinguishment in each test was accomplished with addition of remotely operated fire monitor nozzles. The protection strategy intentionally separated the evaluation of automatic sprinklers and manually operated fire monitor nozzles. The goal was to first determine the sprinkler performance in suppressing or extinguishing the initial fire, then to add fire monitors if additional manual intervention was needed to achieve final extinguishment. An example of the coupled protection strategy is shown in Fig. 1.

The monitor was set to provide a straight stream using the adjustable nozzle to maximize the volume of water reaching the targeted area. A discharge pressure of ~ 5.9 bar (85 psi) resulted in an approximate flow rate of 760 l/min (200 gpm) each.

The location of the monitors was intended to address worst-case position to establish confidence that successful results could be also be achieved under different installation conditions. Horizontally, two monitors were located on opposing sides of the storage grid, with the target goal to cover an approximate 930 m^2 (10,000 ft^2) protected area. The actual separation between monitors was limited to ~ 34 m (110 ft), representing a protected area of ~ 560 m^2 (6,000 ft^2), due to limitations on lab size.

Vertically, the minimum monitor height was set to 1.5 m (5 ft) above the top of the grid to be consistent with manufacturer specification for ceiling clearance. Lower throw angles, i.e., closer to the top of the storage grid, were shown to make targeting less effective and cause greater water stream breakup compared to higher throw angles. For Test 5, the monitors were elevated an additional 2.1 m (7 ft) which highlighted the benefit of a higher throw angle.

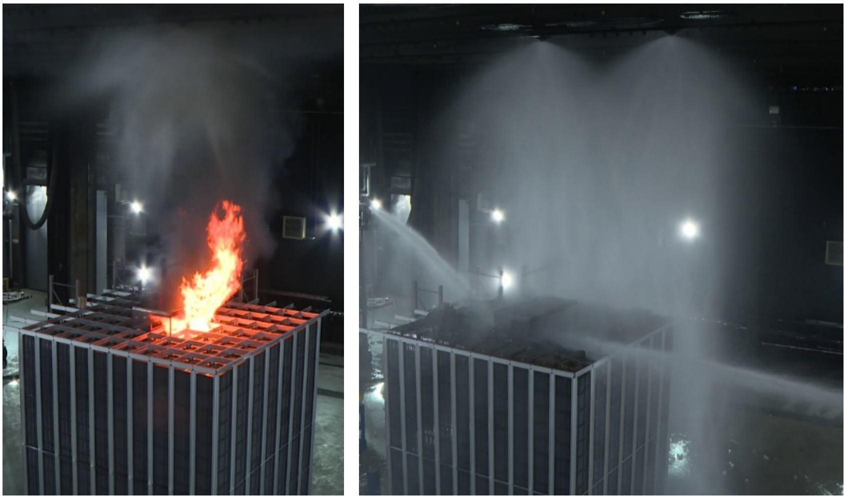

Fig. 1: Photos of Test 4 conducted with three robots located above the ignition area. The fire at first sprinkler operation shown on left and coupled operation of sprinklers and fire monitors shown on right.

Test 2 additionally evaluated the effectiveness of non-combustible vertical barriers to prevent flame spread when used in conjunction with the protection strategy. Two adjacent walls of the storage array were covered with 0.91 mm (0.036 in) thick, i.e., 20-gage, sheet steel that was fastened to the outside of the aluminum columns. All seams were overlapped by at least 76 mm (3 in) and sealed with silicone sealant.

The bottom edge of the barrier was bent at a 90° angle and sealed to the floor. This style of barrier installation requires the removal of one stack width of containers from the storage area, however, robot movement along the top grid would not be affected.

The present work has shown that the evaluated automatic sprinkler protection can suppress a fire in at least one type of TL-ASRS, but manual intervention, in the form of fire monitor nozzles or fire hoses, is required to extinguish the fire. Increasing the discharge density in combination with positive installation and operational considerations can reduce the overall fire spread but could not achieve extinguishment without the addition of fire monitor nozzles (or similar protection such as provided by fire service response using hose streams). Properly designed vertical barriers can also be an effective means of limiting fire spread. Accommodations for manual response and a robust pre-incident plan developed with the local fire department are necessary to develop confidence that final extinguishment can be achieved. If any of the three is missing, or not adequate, there will be a high likelihood of an uncontrolled fire.

Further review of the test results is not presented here as each test was evaluated for multiple outcomes. Conclusions were based on the sensitivity of installation and operational guidelines to impact final extinguishment under the following categories: automatic sprinkler protection using ceiling-level sprinklers, manual protection using fixed-in-place fire monitor nozzles, passive protection using vertical barriers, and obstructions to fire protection (such as robots in fire area).

Protection recommendations based on this work have been incorporated into FM Global Property Loss Prevention Data Sheet 8-34, *Protection for Automatic Storage and Retrieval Systems* [5]. These recommendations are drawn based on the present work related to a specific tested system and should not be extended to other TL-ASRS systems. The combined effects of different storage arrangements, including storage height, vertical flue spaces, container materials, storage content and water leakage conditions, and robot design, may significantly change the fire development and protection performance. Therefore, application of conclusions and recommendations from this work to other TL-ASRS system requires dedicated evaluation of the hazard differences and protection effectiveness.

References

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[3] National Fire Protection Association Standard 13, *Standard for the Installation of Sprinkler Systems,* 2010.

[4] FM Global Property Loss Prevention Data Sheet 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities*, Interim Revision, January 2020.

[5] FM Global Property Loss Prevention Data Sheet 8-34, *Protection for Automatic Storage and Retrieval Systems*, Interim Revision, January 2020.