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FDS SIMULATION OF THE COMBINED USE OF SPRINKLERS AND WATER MIST FIRE EXTINGUISHING SYSTEMS

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ABSTRACT

The purpose of this study is to investigate the effect of sprinkler water droplets with relatively large diameter on the movement of several orders of magnitude smaller water mist particles. The aim of the simulation is to analyze the flow field under a 1m x 1m shelf element with installation height of 1.5 m in the middle of the room, with and without n-heptane tray fire, using combined sprinklers and water mist extinguishing systems.

A CFD model, Fire Dynamic Simulator (FDS) version 5.5.3 was used for the numerical simulation. The data obtained from the numerical studies are analyzed.

As a result of the simulation, we have come to the following conclusions: water mist droplets of smaller diameter are forced to flow in the direction of the shelf environment by the sprinkler open-jet. Under the shelf, the velocities are higher than 1 m/s and vigorous turbulence can be observed. Water droplets of the mist can effectively reach a possible fire under tray. The results show that in the combined system, the sprinkler and water mist droplets can enhance each other's effects.

[1].INTRODUCTION

Water has favorable physical properties for fire suppression. Its high heat capacity and high latent heat of vaporization can absorb a significant quantity of heat from flames and fuels. Water also expands considerably when it evaporates to steam, which results in the dilution of the surrounding oxygen and fuel vapors. With the formation of fine droplets, the effectiveness of water in fire suppression is increased, due to the significant increase in the surface area of water that is available for heat absorption and evaporation [1].

In fixed fire extinguishing systems, water is generally used in sprinklers and water mist in fire suppression equipment. Between the two methods, primarily the rate of flow, the size of water droplets, and the droplet size distribution is the difference.

Standard sprinkler-sprays contain larger than 1 mm diameter droplets in high proportion. The water mist consists of fine droplets, where 99% of the droplets are less than 1mm in diameter as defined in NFPA 750 [2]. Due to the very fine dispersion, the water mist can exhibit gaseous-like behavior and superior mixing characteristics

In regard to the quantitative characterization of sprays, four factors are needed to properly characterize a water spray for fire suppression purposes. These are: drop size distribution (diameter and range), spray flux density, spray angle, spray momentum. The mentioned set of parameters has a direct connection to suppression mechanisms [3].

Droplet trajectory and evaporation rate are mainly governed by the interaction between the sprayed flow (droplets) and the surrounding fluid (momentum, mass and heat transfer). These phenomena are significantly affected by dynamics of the fluid flow, that means velocity and temperature, together with the fluid properties (i.e.: viscosity and density). Fire suppression is basically governed by these parameters.

In case of fire, the whole multiphase flow is made of dispersed droplets, generated vapor, fire-induced air flow and spray-induced air flow. Multiphase fluid dynamics strongly affects fire-suppression performance and it may be described through the classic relations on mass, momentum and energy conservation for each phase [4,5,6].

Water mist systems mainly work by flame extinguishing where the droplets evaporate and lower the flame temperature. The area of surface contact between water and the surrounding hot gases increases with decreasing droplet size. However, very small droplets are rapidly decelerated, and may have difficulties in penetrating a flame zone. In other cases, a high percentage of small water droplets enter the fire plume or flames, rapidly evaporate and contribute to the extinction. Droplet size seems to be

one of the determining parameters in judging the efficiency of fire suppression [7,8,9]**.**
In dense spray, the drops can be in interactions. Influence on each other usually is significant if the separations of droplets are smaller than 10 radii ($10d_p$).

The effect of neighbors will become important with increasing dispersed-phase volume fraction.
In this respect, the flow can be divided into three sections [10].
- collision-free flow (dilute phase flow);
- collision-dominated flow medium (concentration flow);
- contact-dominated flow (dense phase flow).

Attempts can be found in the literature to describe the water droplets collisions. However, in the absence of conclusive data, the effect of neighbor particles or droplets on interphase interactions has been difficult to quantify, these interactions are usually neglected for flows with dispersed-phase volume fraction less than 10% [11,12,13].

The rapid development in computer technology has permitted more sophisticated modeling of the dynamics of fires. In particular, it is now possible to include the effects of water sprays on the fire spread. For example, the Fire Dynamics Simulator (FDS) developed at the National Institute of Standards and Technology (NIST) is used to predict large-scale fire phenomena in a variety of fire scenarios. However, including the effect of sprinkler droplets and water mists on the fire dynamics is necessary to provide characteristics of the water spray produced by the active system devices.

In this paper, using numerical simulation, we investigate what influence the flow of larger (at least 1 mm) droplets has on the water mist (35.5μm mean diameter) distribution.

[2]. **METHODS AND DISCUSSION**

In this work, Fire Dynamic Simulator (FDS) 5.5.3, Rev.: 2012.1.1221 was used for the numerical simulation.

Computational domain and basic data

We placed the computational domain in a 16.9m long, 10.1m wide and 5.1m high room (Figure 1). In simulation, a complex mesh was applied instead of one with homogeneous distribution, i.e. the test field was built from multiple grids of different decompositions. In the close neighborhood of the test space, finer mesh, while farther, coarser mesh was applied. Use of multiple grids is necessary because the algorithm assigns each grid to a separate computer core. The space is divided into 7 grids. Each grid has a different decomposition. Typically, cells of 20cm were applied in the field while, near the test space, 10cmx 5cm cells were used. Close to the sprinklers, cells are column-shaped with a base of 10cmx10cm and height of 5cm. Thus, total number of cells in the whole field is about 400 000.

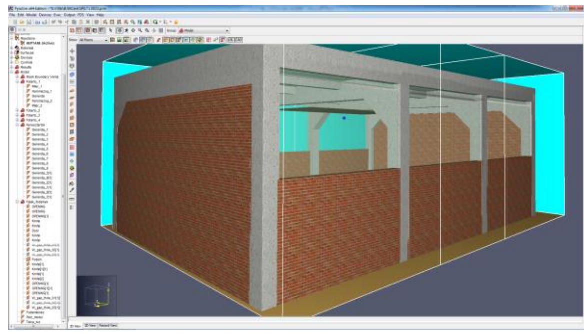

Figure 1: Computational domain.

Standard sprinkler heads and Danfoss 5-12-56-6-27-00 water mist heads were used in the simulations, assuming Rosin-Rammler distribution for the droplets, with parameters of γ=2.4 and σ=0.5 and with mean diameter of 35,53μm for water mist.

Simulations and results

A series of FDS runs was performed for the standard sprinkler system and high pressure water mist system without fire. The runs were aimed at observing the effect of the combined use of sprinkler and water mist on the flow patterns.
Also, a series of FDS runs was performed for the standard sprinkler system and high pressure water mist system against a 2.4 MW Heptane tray fire scenario.
A total of 25 cases ran, and simulation was carried out for the following cases:
- A.VK0.SP1.T1: without fire (A), no water mist (VK0), 1 sprinkler is on (SP1), 1m x 1m shelf element with installation height of 1.5 m in the middle of the room (T1),
- A.VK1.SP0.T1: without fire (A), 1 water mist is on (VK1), no sprinkler (SP0), 1m x 1m shelf element with installation height of 1.5 m in the middle of the room (T1),
- A.VK1.SP1.T1: without fire (A), 1 water mist is on (VK1),1 sprinkler is on (SP1), 1m x 1m shelf element with installation height of 1.5 m in the middle of the room (T1),
- A.VK2.SP2.T1: without fire (A), 2 water mist heads are on (VK2),2 sprinkler heads are on (SP2), 1m x 1m shelf element with installation height of 1.5 m in the middle of the room (T1),

- B.VK0.SP1.T1:with tray fire (B), no water mist (VK0), 1 sprinkler is on (SP1), 1m x 1m shelf element with installation height of 1.5 m in the middle of the room (T1),
- B.VK1.SP0.T1: with tray fire (B), 1 water mist is on (VK1), no sprinkler (SP0), 1m x 1m shelf element with installation height of 1.5 m in the middle of the room (T1),
- B.VK1.SP1.T1: with tray fire (B), 1 water mist is on (VK1),1 sprinkler is on (SP1), 1m x 1m shelf element with installation height of 1.5 m in the middle of the room (T1),
- B.VK2.SP2.T1: with tray fire (B), 2 water mist heads are on (VK2), 2 sprinkler heads are on (SP2), 1m x 1m shelf element with installation height of 1.5 m in the middle of the room (T1),

A water-mist nozzle was placed at a height of 4.8m.

Behavior without fire

Examination without fire aimed at investigation of distribution of sprinkler and water mist droplets.

Case 1: A.VK0.SP1.T1

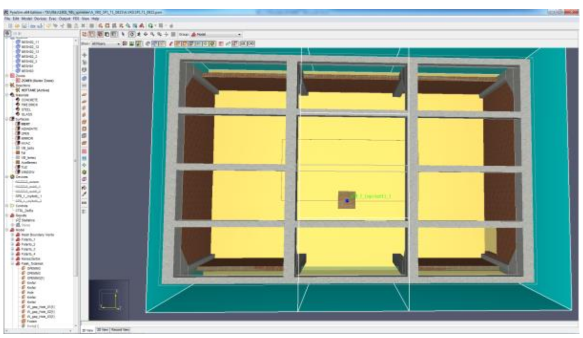

Figure 2: A.VK0.SP1.T1 - test model.

In this arrangement, a sprinkler was placed over the shelf element.

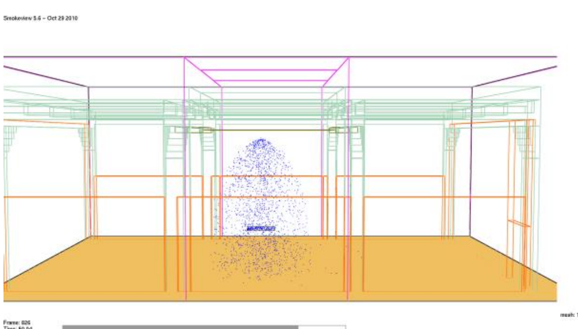

Figure 3: A.VK0.SP1.T1 - sprinkler flow pattern.

In the model without fire, the flow pattern generated by droplets with average diameter of 500μm moving downwards shows intensive turbulent flow with a velocity of 1.8m/s in the space under the tray.

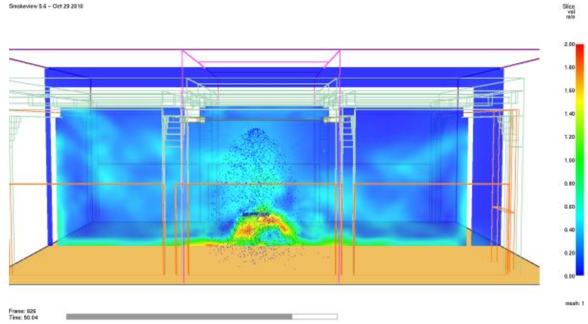

Figure 4: A.VK0.SP1.T1 - velocity field in vertical plane.

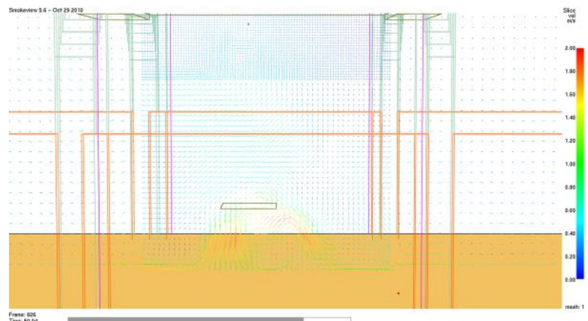

Figure 5: A.VK0.SP1.T1 - velocity vectors in vertical plane

Case 2: A.VK1.SP0.T1

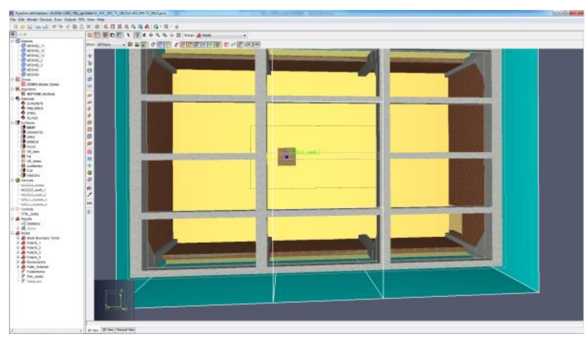

Figure 6: A.VK1.SP0.T1 - test model.

In this arrangement, a water mist head was placed over the shelf element.

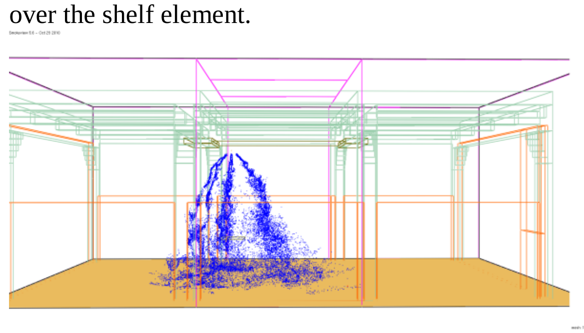

Figure 7: A.VK1.SP0.T1 - water mist flow pattern.

Both figures below reveal that the smaller water quantity and the velocity coming from a larger head results in generation of a turbulent velocity field of approx. 1m/s under the tray.

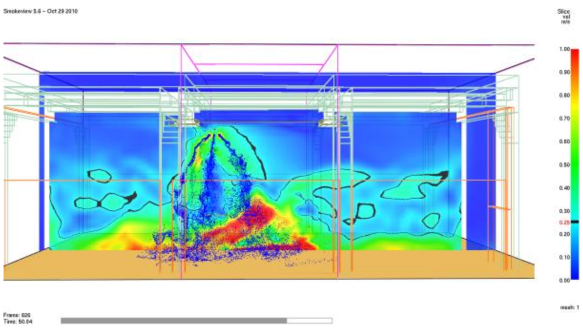

Figure 8: A.VK1.SP0.T1 - velocity field.

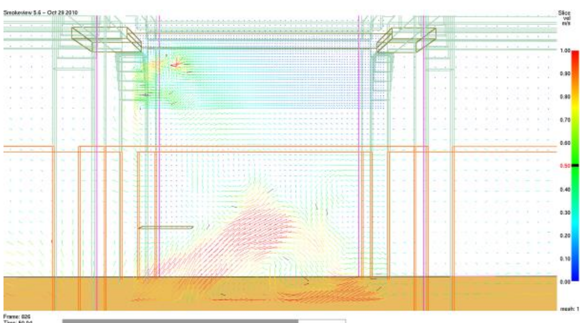

Figure 9: A.VK1.SP0.T1 - velocity vectors.

Case 3: A.VK1.SP1.T1

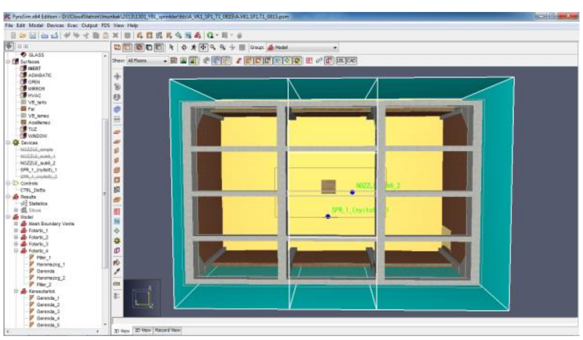
Figure 10: A.VK1.SP1.T1 - test model

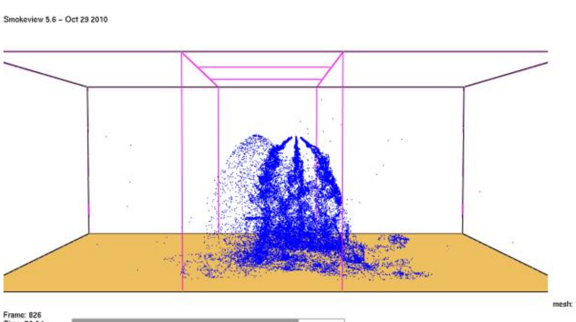

Figure 11: A.VK1.SP1.T1 - combined flow pattern of water mist and sprinkler.

In this test arrangement, one sprinkler head and one water mist head were placed over a shelf element, each at 1.5m from the vertical symmetry axis of the shelf element.

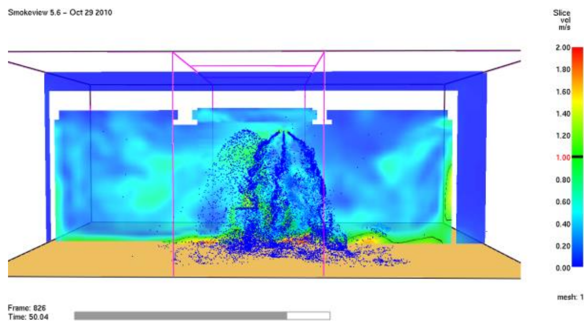

Figure 12: A.VK1.SP1.T1 - velocity field.

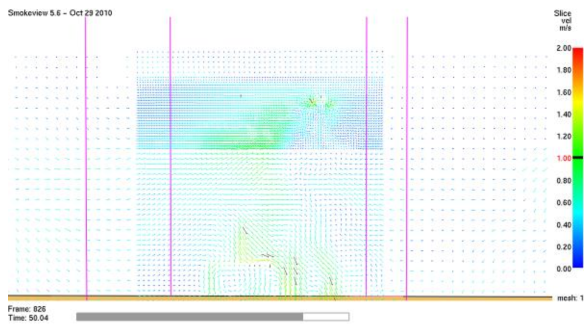

Figure 13: A.VK1.SP1.T1 - velocity vectors.

Results of starting them together: properties of both higher local sprinkler velocities and more balanced water mist velocities can be observed.

Case 4: A.VK2.SP2.T1

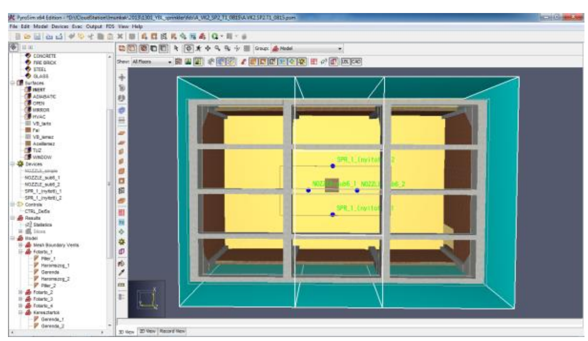
Figure 14: A.VK2.SP2.T1 - test model.

In this test arrangement, two sprinkler heads and two water mist heads were placed over a shelf element, each at 1.5m from the vertical symmetry axis of the shelf element.

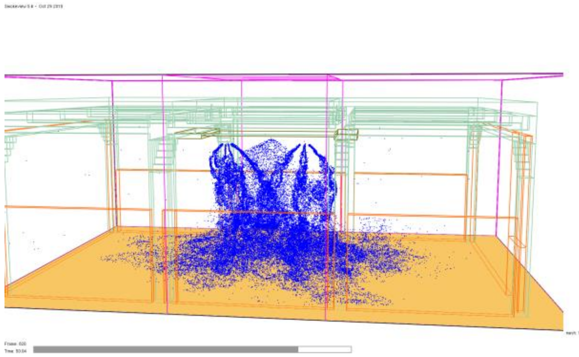

Figure 15: A.VK2.SP2.T1 - water droplets near the shelf element.

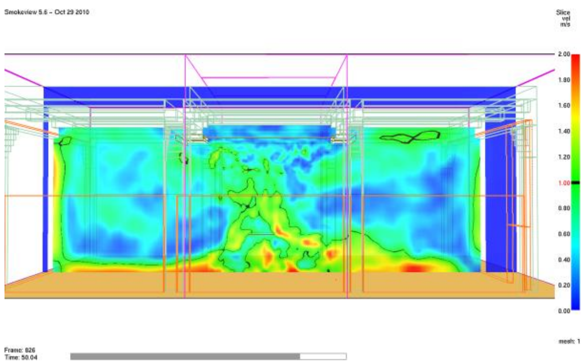

Figure 16: A.VK2.SP2.T1 - velocity field.

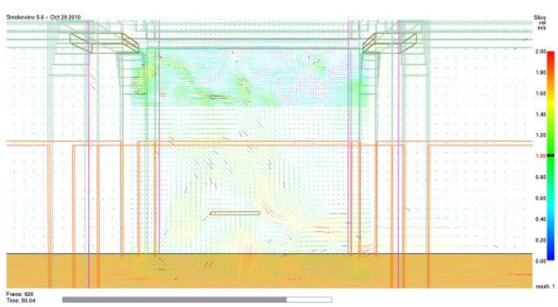

Figure 17: A.VK2.SP2.T1 - velocity vectors.

The figures above show that velocities of 1m/s or above are generated with intensive turbulence under the tray.

Comparison of cases without fire:
Cases without fire were investigated with the help of a velocity field at a height of 1.4m.

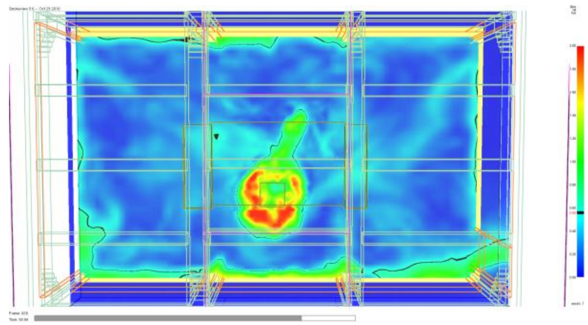

Figure 18: A.VK0.SP1.T1 - velocity field.

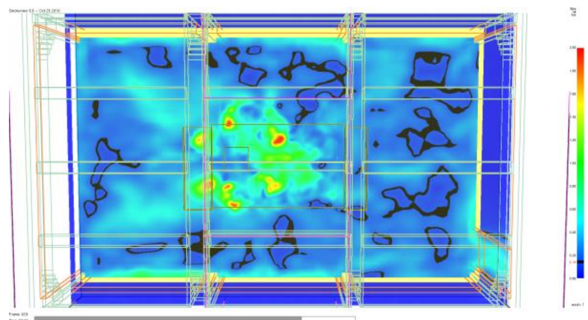

Figure 19: A.VK1.SP0.T1 - velocity field.

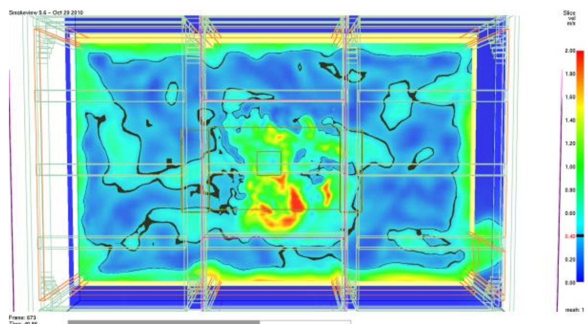

Figure 20: A.VK1.SP1.T1 - velocity field.

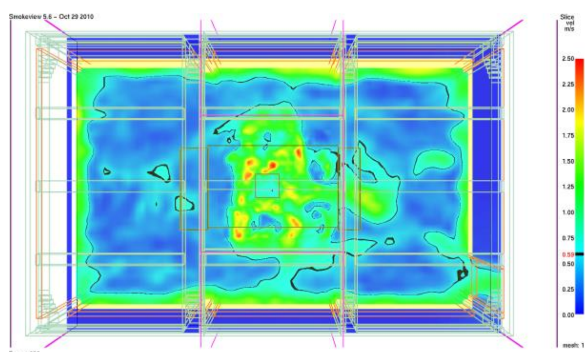

Figure 21: A.VK2.SP2.T1 - velocity field.

Inserting more number of heads in the model results a quicker growing velocity field and more balanced velocity under the tray.

Tray fire behavior with full volume flow rates

The examination aimed at studying behavior at full fire extinguishing capacity of distribution of sprinkler and water mist droplets.

Case 1: B.VK0.SP1.T1

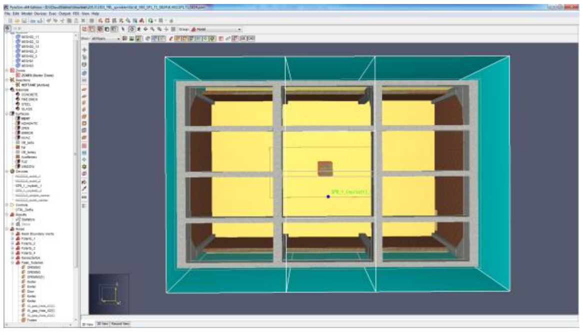

Figure 22: B.VK0.SP1.T1 - test model.

In this arrangement, one sprinkler was placed at 1.5m from the axis of the shelf element. This head was started 5s after lighting the fire.

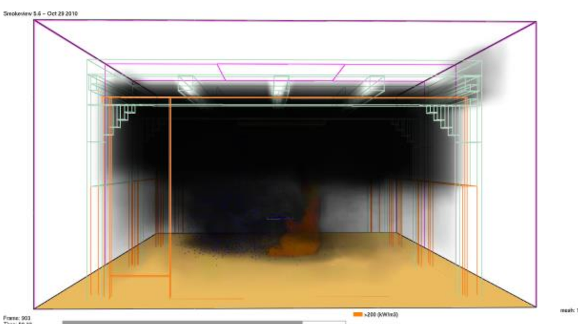

Figure 23: B.VK0.SP1.T1 - sprinkler flow pattern, smoke propagation, fire power per unit volume.

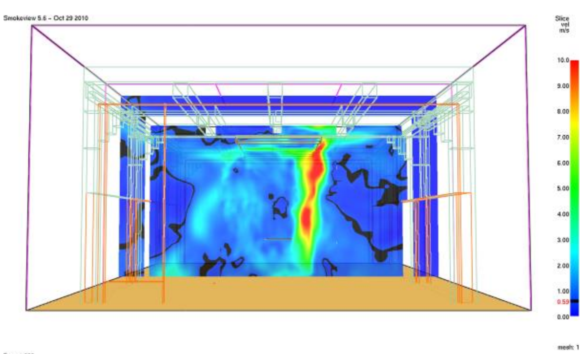

Figure 24: B.VK0.SP1.T1 - velocity field in vertical plane.

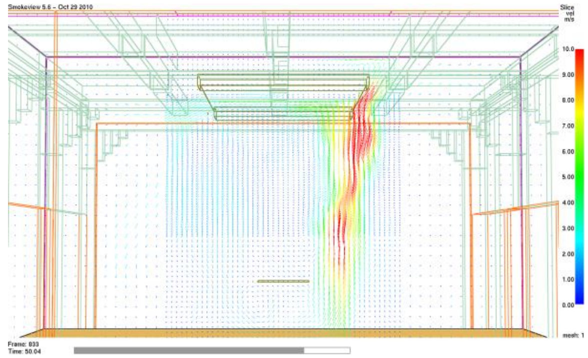

Figure 25: B.VK0.SP1.T1 - velocity vectors in vertical plane.

Test plane is in the common axis of the fire and the sprinkler. Analyzing the scalar field and vector space, we can state that plume emerging from fire under the tray generates a buoyancy of 10m/s while droplets escaping from sprinkler head move with a velocity of 0.5-0.6m/s near the fire center. Sprinkler droplets change the shape of the plume. It can be seen that the plume escapes from beneath the tray on the side being farther from the sprinkler. The plume and impulse forces generated by sprinkler droplets form a turbulent space under the tray.

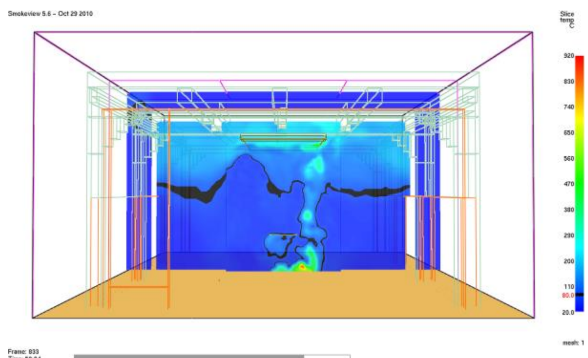

Figure 26: B.VK0.SP1.T1 - temperature field in vertical plane.

Temperature field was investigated vertically in the common axis of the fire and sprinkler. 80°C isotherm is indicated with black line in the figure. It can be seen that temperature is about 900°C locally near the fire. Due to the intensive precipitation, the ambient temperature is 80°C in the space under the tray (farther from the plume). The temperature is below 80°C also in the sprinkler flow pattern range. The 80°C isotherm lies directly under the sprinkler head. Smoke delivered by plume towards the ceiling returns toward the bottom in the sprinkler flow pattern range

Case 2: B.VK1.SP0.T1

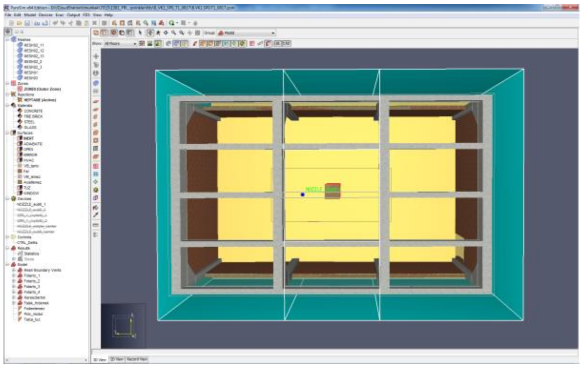

Figure 27: B.VK1.SP0.T1 - test model.

In this arrangement, one water mist head is placed at 1.5m from the axis of the shelf element, and the head was started 5s after lighting the fire.

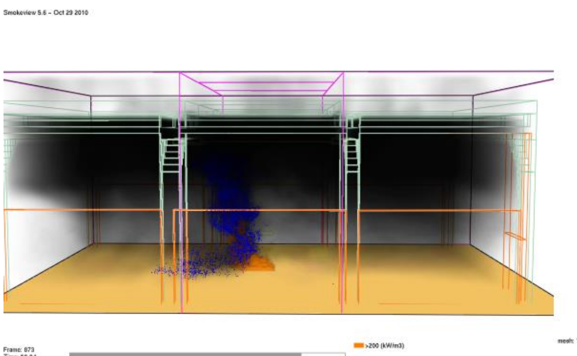

Figure 28: B.VK1.SP0.T1 - water mist flow pattern, smoke propagation, fire power per unit volume.

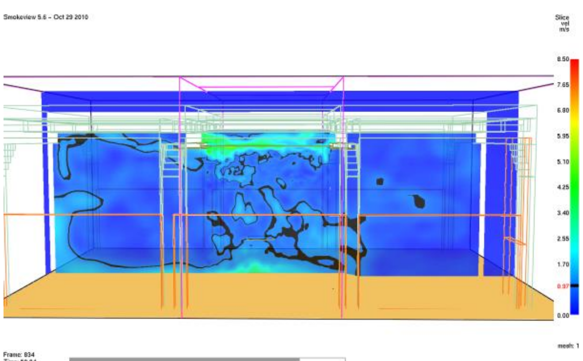

Figure 29: B.VK1.SP0.T1 - velocity field in vertical plane.

Test plane is in the common axis of the fire and the water mist head. Analyzing the scalar field and vector space, we can state that plume emerging from fire under the tray generates a buoyancy of 8.5m/s but the classic buoyancy plume is not generated. The plume and impulse forces generated by water mist build up a turbulent space under the tray.

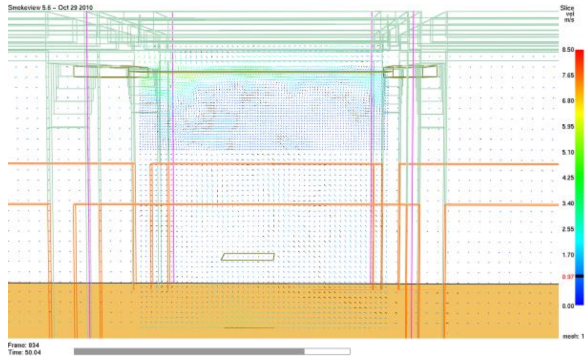

Figure 30: B.VK1.SP0.T1 - velocity vectors in vertical plane.

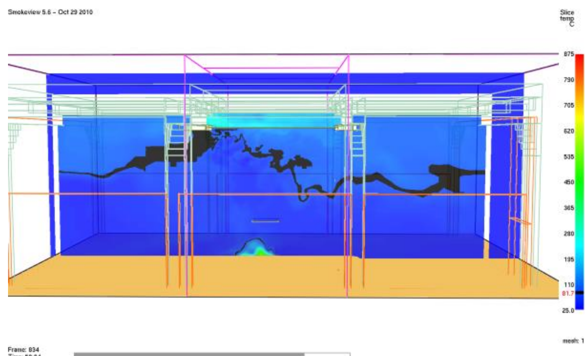

Figure 31: B.VK1.SP0.T1 - temperature field in vertical plane.

Temperature field was investigated vertically in the common axis of the fire and sprinkler. 80°C isotherm is indicated with black line in the figure. It can be seen that temperature is about 350°C locally near the fire. Due to the water mist, the ambient temperature is below 80°C in the space under the tray (farther from the plume). The temperature is below 80°C also in the water mist flow pattern range. The 80°C isotherm lies directly under the water mist head. Smoke deflection due to water mist can also be seen.

Case 3: B.VK1.SP1.T1

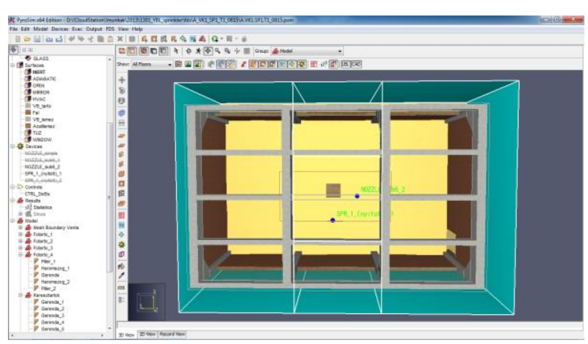

Figure 32: B.VK1.SP1.T1 - test model.

In this arrangement, one sprinkler and one water mist head are placed, each at 1.5m from the axis of the shelf element, and the heads were started 5s after lighting the fire.

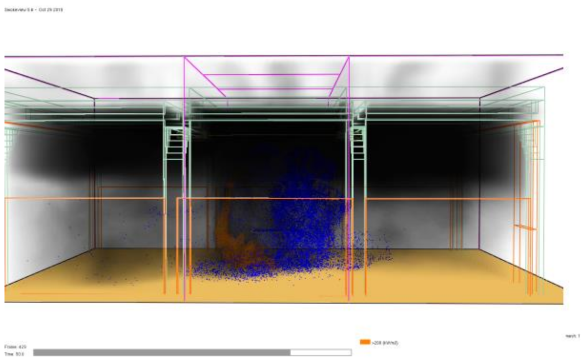

Figure 33: B.VK1.SP1.T1 - water mist flow pattern, smoke propagation, fire power per unit volume.

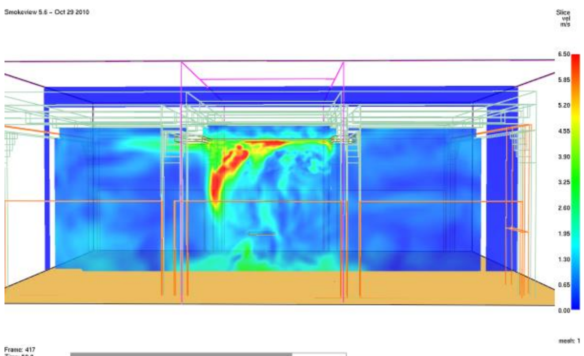

Figure 34: B.VK1.SP1.T1 - velocity field in vertical plane.

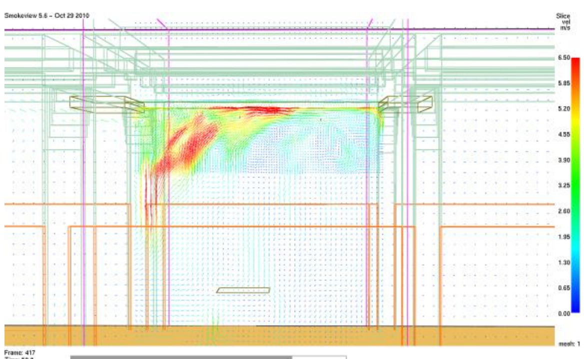

Figure 35: B.VK1.SP1.T1 - velocity vectors in vertical plane.

Test plane is in the common axis of the fire and the water mist head. Analyzing the scalar field and vector space, we can state that plume emerging from fire under the tray generates a buoyancy of 8.5m/s but the classic buoyancy plume is not generated. The plume and impulse forces generated by water mist build up a turbulent space under the tray.

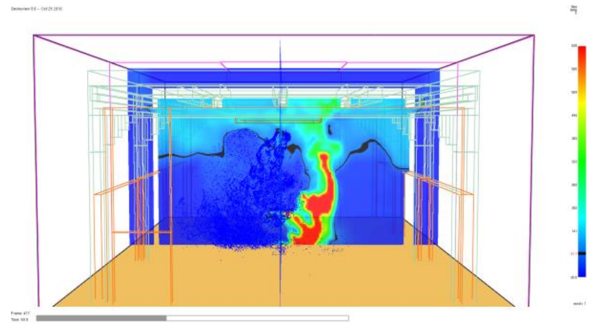

Figure 36: B.VK1.SP0.T1 - temperature field in vertical plane.

Temperature field was investigated vertically in the common axes of both the sprinkler and the fire and water mist head and the fire. 80°C isotherm is indicated with black line in the figure. It can be seen that temperature is locally about 350°C near the fire. Due to the water mist, the ambient temperature is below 80°C in the space under the tray (farther from the plume). Sprinkler and water mist acting against the fire asymmetrically deflect the plume from beneath the tray.

Case 4: B.VK2.SP2.T1

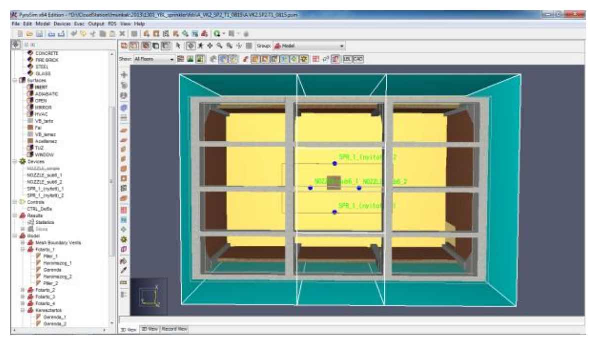

Figure 37: B.VK2.SP2.T1 - test model.

In this arrangement, two sprinklers and two water mist heads are placed, each at 1.5m from the axis of the shelf element, and the heads were started 5s after lighting the fire.

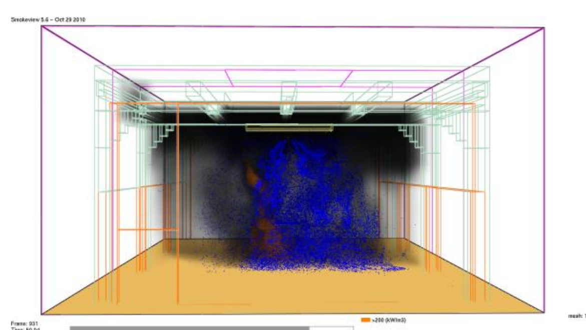

Figure 38: B.VK2.SP2.T1 - water mist flow pattern, smoke propagation, fire power per unit volume.

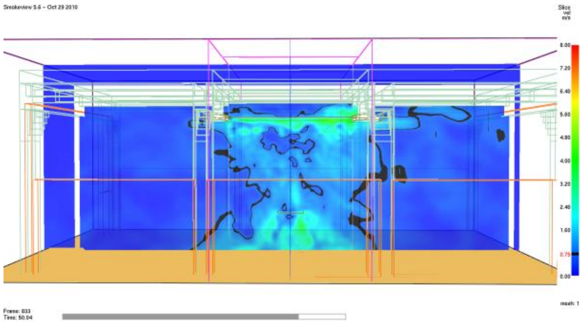

Figure 39: B.VK2.SP2.T1 - velocity field in vertical plane.

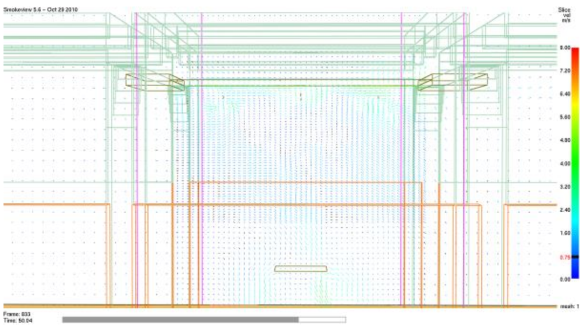

Figure 40: B.VK2.SP2.T1 - velocity vectors in vertical plane.

Test plane is in the common axis of the fire and the water mist head. Analyzing the scalar field and vector space, we can state that plume emerging from fire under the tray generates a buoyancy of 8.0m/s. The plume and impulse forces generated by water mist build up a turbulent space under the tray.

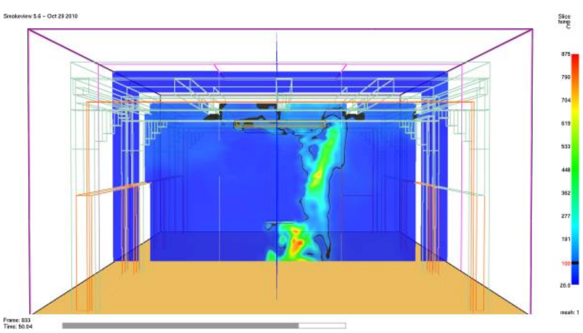

Figure 41: B.VK2.SP2.T1 - temperature field in vertical plane.

Temperature field was investigated vertically in the common axes of both the sprinkler and the fire and water mist head and the fire. 100°C isotherm is indicated with black line in the figure. It can be seen that temperature is about 350°C locally near the fire. Due to the water mist, the ambient temperature is below 80°C in the space under the tray (farther from the plume). Outside the fire and its plume, the ambient temperature is about 20°C.

Comparison of cases with fire:

For comparison of the different cases, a temperature field and a velocity field are defined in the plane under the tray.

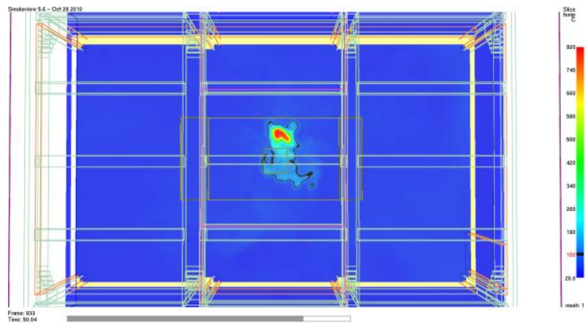

Figure 42: B.VK0.SP1.T1 - temperature field.

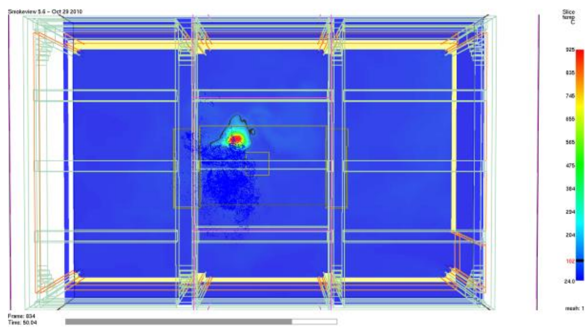

Figure 43: B.VK1.SP0.T1 - temperature field.

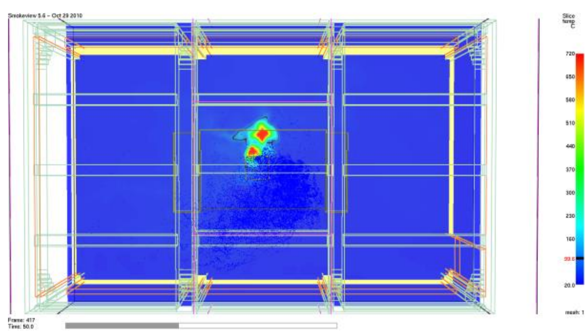

Figure 44: B.VK1.SP1.T1 - temperature field.

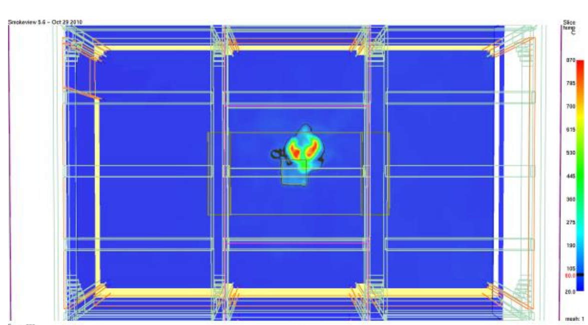

Figure 45: B.VK2.SP2.T1 - temperature field.

When increasing number of heads, the temperature under the plume is decreasing.

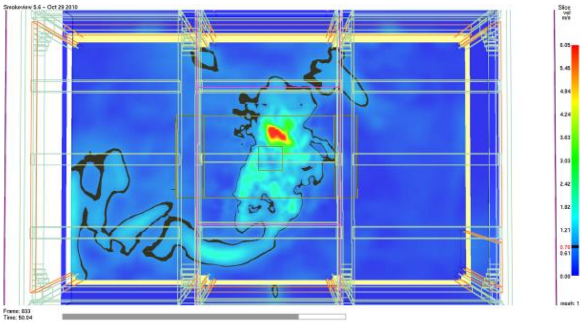

Figure 46: B.VK0.SP1.T1 - velocity field.

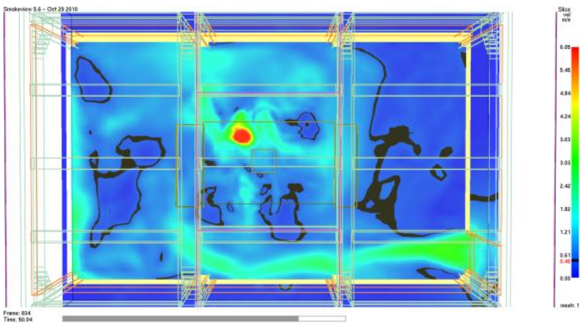

Figure 47: B.VK1.SP0.T1 - velocity field.

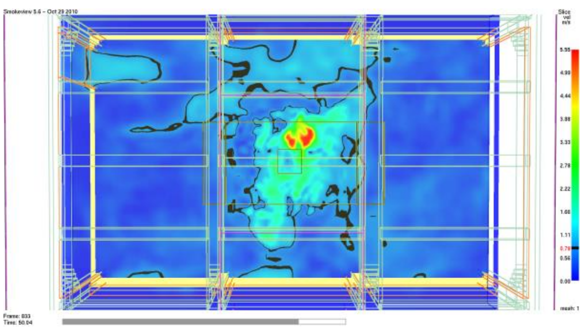

Figure 48: B.VK2.SP2.T1 - velocity field.

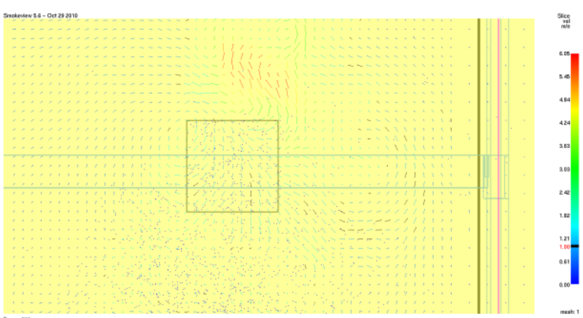

Figure 49: B.VK0.SP1.T1 - velocity vectors near the test tray.

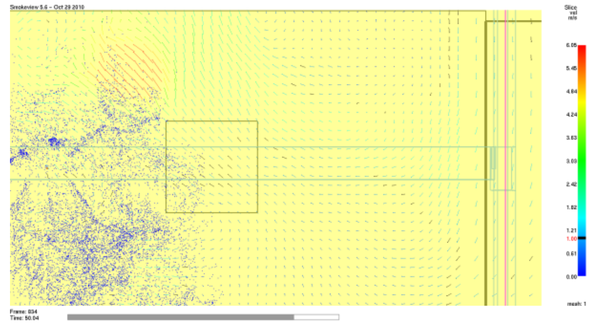

Figure 50: B.VK1.SP0.T1 - velocity vectors near the test tray.

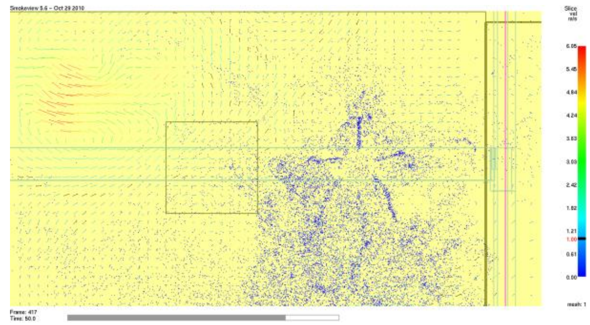

Figure 51: B.VK1.SP1.T1 - velocity vectors near the test tray.

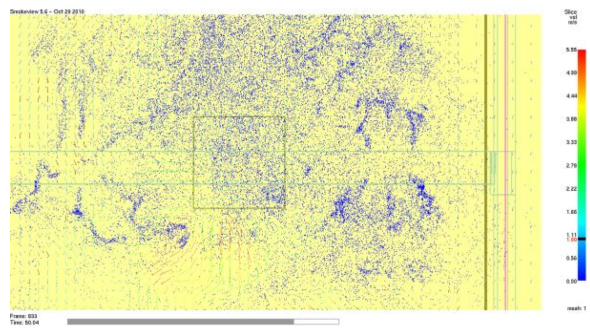

Figure 52: B.VK2.SP2.T1 - velocity vectors near the test tray.

[3].**<u>CONCLUSIONS</u>**

The plume generated by the fire significantly modifies the water mist field. Droplets up to 30µm, existing in form of precipitation, are deflected from their trajectories by the buoyancy generated by the plume moving with 5-6 m/s. Plumes of fires of 2-3 MW deflect small droplets from the core of flame, thus, they cannot reach the center of the fire. In the case of sprinklers with average droplet sizes of 500µm, this effect can be observed less.

In the asymmetric test models both with sprinkler and water mist, plume trajectory was deflected to the opposite direction. This means that symmetric test arrangements shall be preferred. Advisably, in measurement configuration, heads shall symmetrically circle the core of flame both in the model with sprinkler alone and water mist alone. In one single test model (B.VK2.SP2.T1), the plume could build up even when sprinklers and water mist heads circled the center of fire symmetrically.

When increasing number of sprinklers and water mist heads (meaning more quantity of fire-fighting water), decreasing ambient temperature can be observed near the flame core, plume and tray being investigated. Near the sprinklers and water mist heads, significant temperature drop can be seen.

Impulse force of sprinklers deflects smoke accumulated on the ceiling to the occupational zone more effectively. When sprinklers and water mist heads work together, this smoke deflecting effect is somewhat smaller. This simulation result shall be investigated with introduction of additional test planes. Examination shall be extended to analysis of the extinction factor.

When water mist and sprinkler worked together, impulse force generated by the mass of sprinkler droplets forced also water mist droplets to move closer to center of fire. As the Lagrangian model does not model agglutination of droplets, this test result shall be examined by real measurements.

The previous simulation result opens up a new examination arrangement: when placing sprinkler and water mist heads next to each other, the effect described in the previous paragraph might be enhanced.

Based on the results shown above, for analysis of fire extinguishing effect of water mist–sprinkler, introduction of additional examination planes is recommended:

- Volume fraction of steam in the plane of the tested tray near the center of the fire – for examining access of vapor to fire
- Oxygen concentration in the plane of the tested tray near the center of the fire – for analyzing effect of deoxidation

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