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The effect of smoke evacuation system on sprinkler performance in Conference Halls by using CFD programs

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ABSTRACT : *High ceiling buildings with large volume space, such as conference halls, theaters, and covered malls, need to use many systems to control fire. According to the level of hazard, a wet sprinkler system is used in this work to fight fire in a building which include high fire load which produces and a large amount of smoke. This work seeks to highlight the importance of smoke management system, the effect of smoke management system on water mist system based on two main criteria. First one is thermal effect through HRR measurements and temperature profile, the second one is toxicity effect through CO concentrations, the system is analyzed numerically by FDS model (Fire dynamic simulation). The results of this work compared to previous studies' results in details below.*

KEYWORDS: *smoke evacuation, sprinklers performance, CFD, Water Mist, smoke management.*

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I. INTRODUCTION

The interaction between the smoke management system and the sprinkler system was discussed in previous studies through analyzing many parameters. Recently, water mist systems may appear to be a reasonable compromise compared to traditional safety sprinkler system for building safety and against flames. The mist formed by the exit of water droplets under high pressure penetrates rapidly with the smoke layer and works to homogenize the temperature. During this penetration, sprinkler performance may be affected by smoke management system due to drag force and heat transfer from smoke layer to sprinkler spray. The effect of this system is studied through its main factors like water flow rate, droplet diameter and nozzle location. In the aforementioned buildings, smoke exhaust should be mechanical intended to move smoke from the smoke zone to the exterior of the building. It is used with the usual firefighting system to get rid of toxic gases and combustion products (CO) that may cause loss of lives.

Some previous studies talked about the interaction between smoke management system and water mist system, and the effect of one to another according to different parameters. Stratification of smoke layer was analyzed through velocity, temperature, opacity numerically and experimentally (Blanchard &Morlon, 2015). Morlon´s experiment have been conducted on smoke flowing in a natural ventilated corridor, investigating the de-stratification effect in free burn and with water mist system activation.

II. NUMERICAL SIMULATION

CFD- simulations provide a tool to study fundamental fluid dynamics and can be used to solve practical problems in fire protection engineering, with particular interest in smoke and heat transport from fires and in sprinkler activation studies. FDS is developed by NIST in the simulations of the Fire Dynamics Simulator FDS version UTRC_FDS_7901 is used, Smoke view is a companion visualization program that can be used to display the output of FDS. The FDS model includes a hydrodynamic model where the turbulences are treated, a combustion model, radiation transport model and a conductive heat transfer model. For the present application. The FDS model solves numerically a LES (large eddy simulations) form of the Navier-Stokes's equations appropriate for low speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. The main input data in the simulation are given in Table1. The real scale model is a main hall in the conference building as shown in Fig.1. This hall has a floor area of 784 m^2 and 12m height. It has mechanical smoke management system through 4 grills on the walls near the ceiling. The test was connected to 12 meshes in which we analyzed the impact of water mist on smoke flow. A water fog system provided by the high-pressure pump system which delivers water under high pressure through steel. Pipes to high pressure water mist nozzles. This means that in the experiment, 15nozzles were activated according to the data given by the manufacturer. Water Mist system parameters do not form part of the original FDS. In the FDS-model construction, a design fire is introduced. This fire scenario resembles that applied in a real fire test, to which the simulation results are compared. The key issue in this model is to show the cooling effect of water mist system on fire suppression which appear in heat release rate decreasing after system activation.

Table 1
Main Input Parameters for the Simulation

Dimension	conference room size: 28x28x12m
Fire load	Fire is modeled with a red box which burns at 500 kw from seat mockup HRR per unit area 300 kw/m2
Smoke management	4 suction grills Grill size: 150x60 cm Flow rate: 5393 m3/hr
water mist	k-factor for nozzle 0.228 m3/h/bar0.5 max. coverage area 16m2 water flux density 0.0108 m3/h/m3

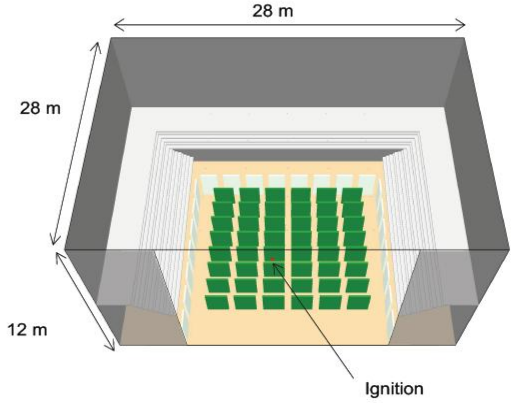
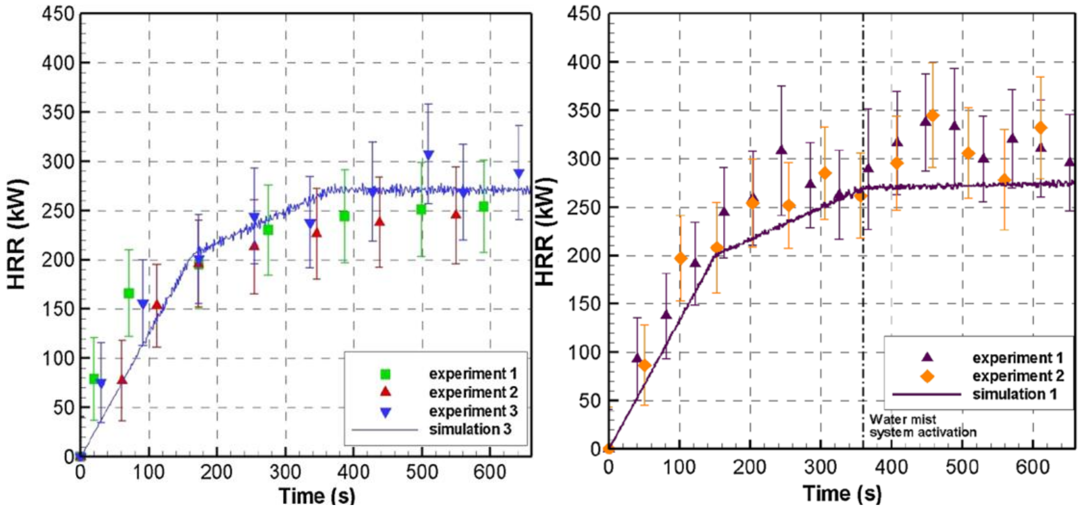


Fig.1 model for a main hall

Fig.2 view form FDS model room

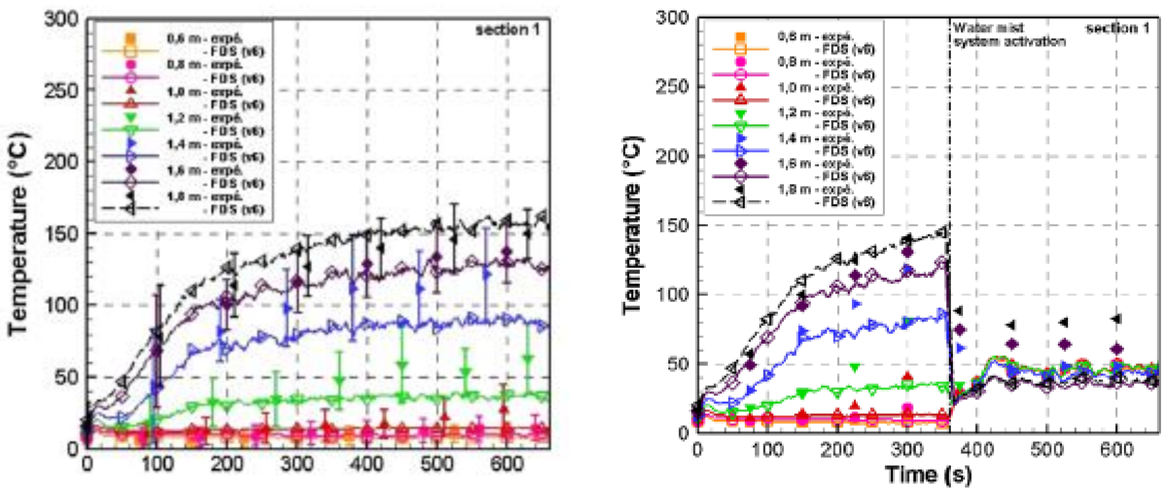
III. VERIFICATION BETWEEN NUMERICAL SIMULATION AND PREVIOUS EXPERIMENTS

According To Morlon, he builds up a real-scale model of a room which was connected to a corridor with an opening in one wall to work as a gravity-smoke evacuation. Constant fire load was produced by heptane's pool. The fire was not directly affected by the mist system. On the other hand, he studied the effect of the water mist system on the smoke layer experimentally and confirmed the results by FDS (2015).



(a) (b)

Fig.3 HRR measurements experimental and numerical



(a) (b)

Fig.4 Temperature profile experimental and numerical

The graph of HRR didn’t give a significant difference with and without the water mist system. Its evolution was nearly the same. On the contrary, the profile temperatures plotted without water mist system for the smoke layer under the sprinkler area soared quickly then remained constant. When the water mist system is activated, instantaneously, the water injection results in a sharp penetration in the distribution of temperature, globally contributing to the homogenization of temperature, much better than before.

According to Morlon, he made a numerical study in which he built up an actual experiment as he measured the HRR 3 times; after that, he used the data as an input data in the simulation of the test with FDS code. In conclusion, according to Morlon’s study, he stated that fire load doesn’t remain constant (2015). As per the researcher's point of view, he popup with new results that differ from Morlon’s study. In addition, it changes due to fire spread in seats mockup. This was reflected on HRR increasing especially with smoke evacuation without mist action, and that is in addition to considering the profile temperature of the smoke layer in the surrounding. Furthermore, heat transfer between the smoke layer and fog, which was evident gradually decreasing in temperature. Also, by measuring CO concentration level, the effectiveness of interaction between smoke management system and water mist system was confirmed and CO level decreased.

IV. RESULTS AND DISCUSSIONS

- ***First scenario: free burn with smoke management system without water mist system*: -**

Comparing results of Fig 3 (a) [7] with Fig 6, it gives the same results with slightly difference at the end of each one. The difference may be related to the variation of room dimensions and the type, distribution of exhaust opening inside the case.

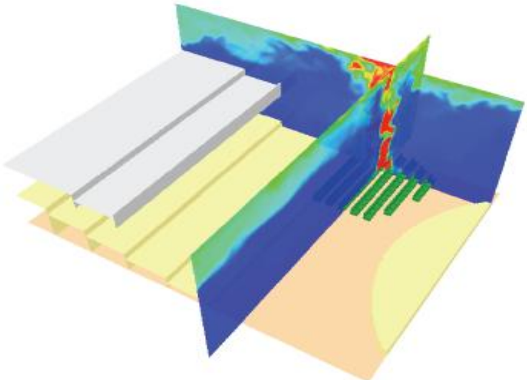


Fig.5 First scenario: free burn with smoke management system without water mist system

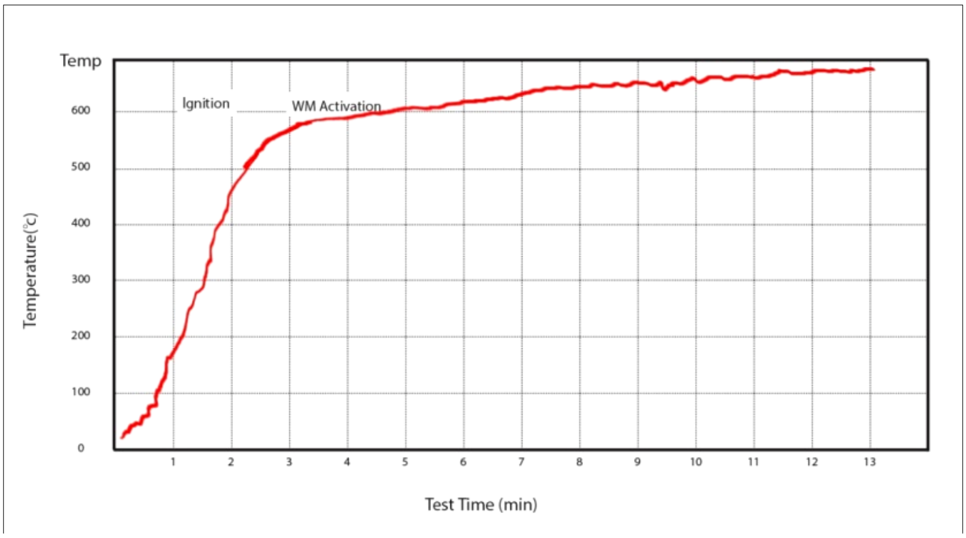


Fig.6 HHR without water mist system

comparing the results of Fig (4, a) [7] with Fig (7), it shows high increasing in temperature profile for smoke layer with activation of smoke management system only. This is related to increasing of fresh air make up which increased oxygen level and chemical reaction. So, temperature continued to rise. The result shows that the necessity of activating water mist system with smoke management system is to avoid the height and control of the fire spread.

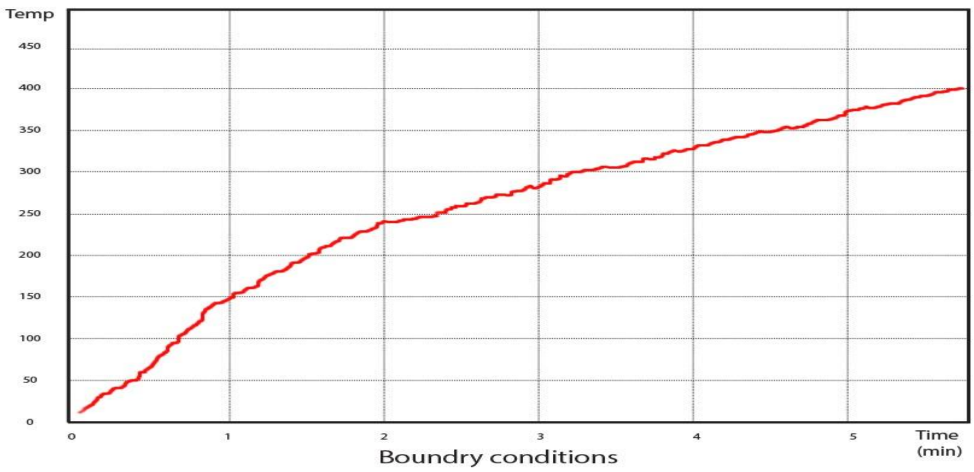


Fig.7 Temperature profile without water mist system

Fig (9) shows increasing of CO concentration without water mist system activation- This shows that there was no cooling effect which affecting on ashes decreasing and inhibition of the chemical reaction that responsible also for increasing the fire level. In addition to, increasing fresh are make-up due to mechanical smoke extraction.

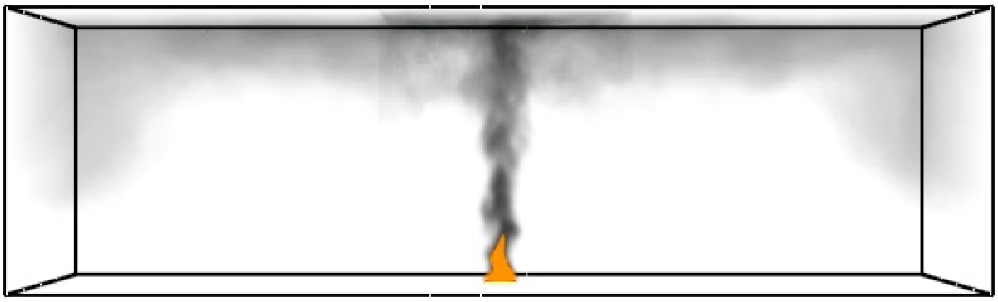


Fig.8 shows increasing of CO concentration without water mist system activation

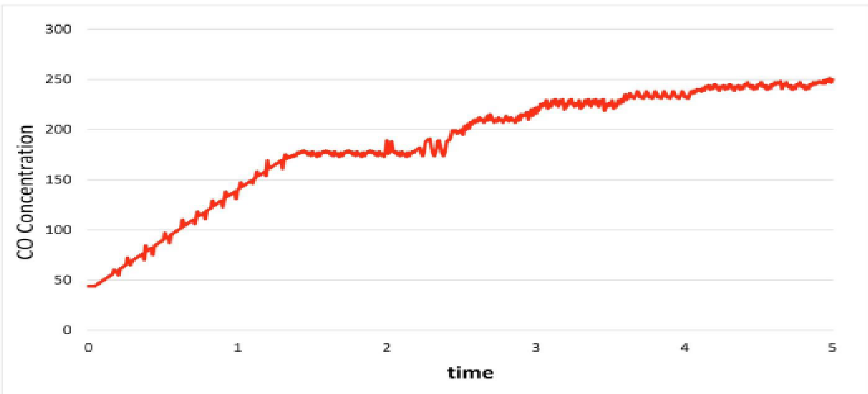


Fig.9 CO concentration level without water mist system

- **Second scenario: free burn with smoke management system and water mist system:**

Meanwhile, comparing results between Fig (10), with Fig.3(b) [7], it gives different outputs. The HRR in Fig (10) decreased when water mist system started to supply mist in void, but in Fig.3(b) the smoke extraction was taken from corridor which is far away from the extinguishing media and area. That means direct and fast cooling effect for fire zone. So, fig (10) should be considered as a real case more than Fig.3(b).

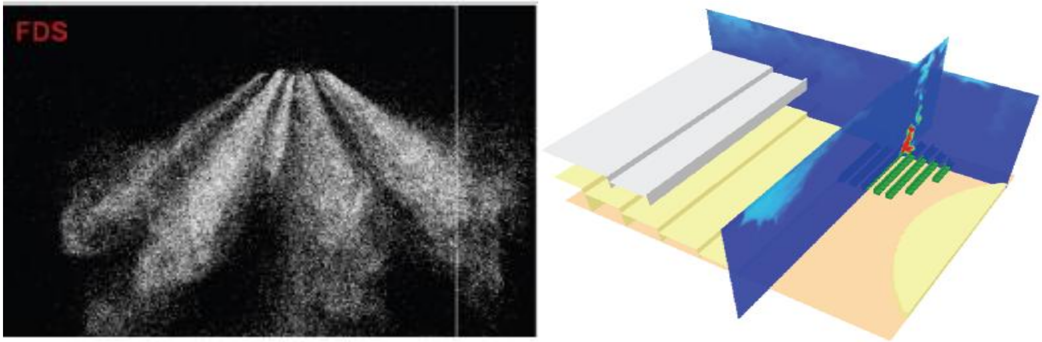


Fig.10 Second scenario: free burn with smoke management system and water mist system:

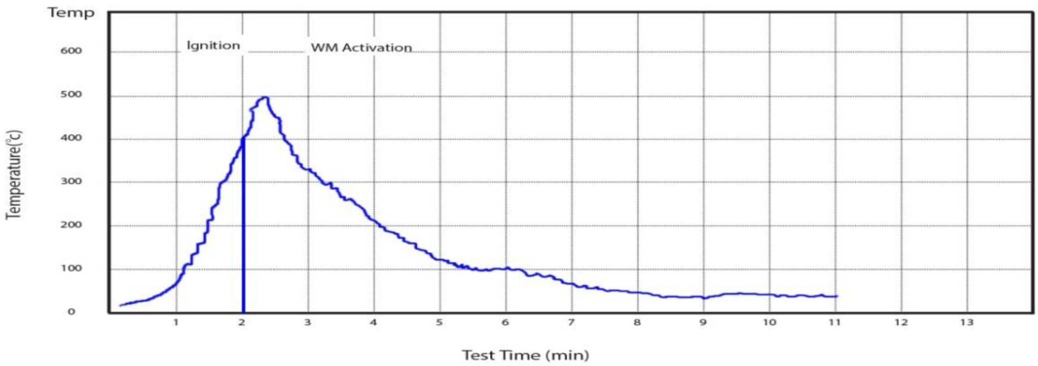


Fig.11 HHR with water mist activation

comparing results between Fig (12), with Fig4(b) [7]- it gives different distribution for smoke layer temperature. The temperature in Fig (12) decreased gradually, and this explains that the rate of heat transfer between the smoke layer and the surrounding of the room takes time for the temperature uniformity to occur. Furthermore, unlike what happens in the area directly below the sprinkler, where the temperature drop was rapid and noticeable.

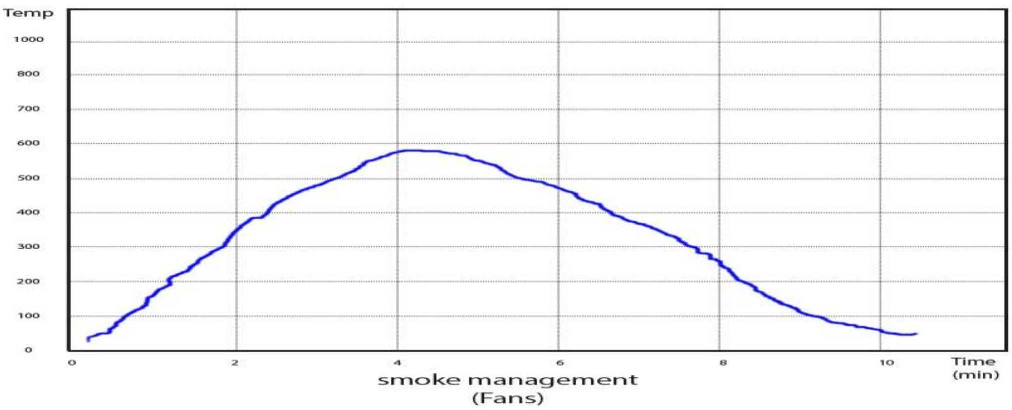


Fig.12 Profile temperature with water mist activation

Fig. 14 shows decreasing of CO concentration with water mist system activation- This is related to cooling effect of mist system which affecting on inhibition of the chemical reaction. Where the water droplets stuck with ashes, which is responsible on CO concentration.

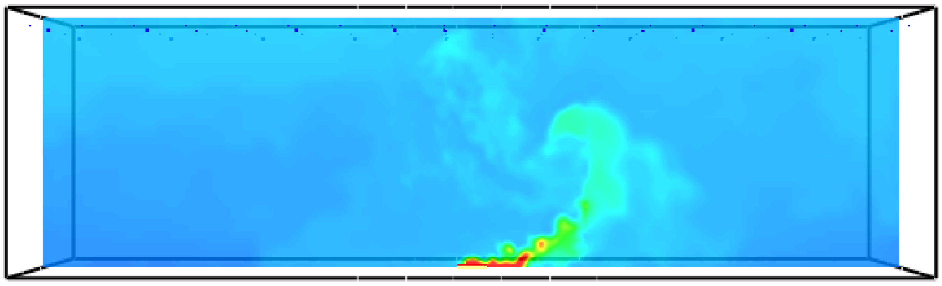


Fig.13 shows decreasing of CO concentration with water mist system activation

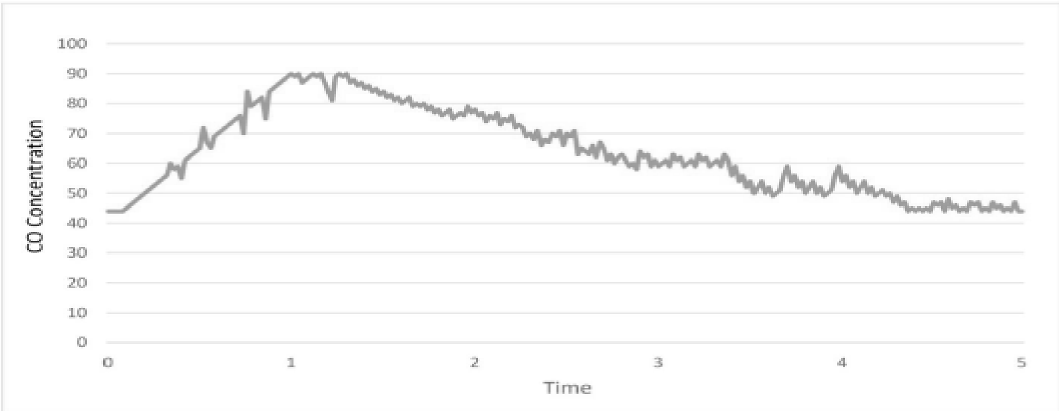


Fig. 14 CO concentration level with water mist system

Finally, this paper presented the effect of smoke management system on sprinkler performance throw thermal measurements (HHR- temperature profile). Moreover, toxicity measurements to confirm the effectiveness and important of mechanical smoke management system in this model. Hence, the interaction between smoke management system and water mist system to control fire and preserve the safety of lives.

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