Journal of Physics:
Conference Series

PAPER • OPEN ACCESS

Tray configuration factors on cable flame spread

To cite this article: David Lázaro *et al* 2024 *J. Phys.: Conf. Ser.* **2885** 012028

Journal of Physics: Conference Series **2885** (2024) 012028 doi:10.1088/1742-6596/2885/1/012028

Tray configuration factors on cable flame spread

David Lázaro[a]*, Pedro G. Lázaro[a], Mariano Lázaro[a], Miguel Ángel Jiménez[b], Daniel Alvear[a]

[a] Universidad de Cantabria, Spain
[b] Consejo de Seguridad Nuclear, CSN, Spain

David Lázaro: lazarod@unican.es

Abstract. Fire propagation in cable trays is a critical concern in the design and safety of nuclear power plants (NPP), as it can facilitate the spread of fire between different enclosures or affect cables necessary to a safety shutdown procedure. While international programs such as CHRISTIFIRE and PRISME have contributed to our understanding through various experimental campaigns, the complexity of the phenomena and the multitude of boundary conditions affecting cable tray scenarios necessitate further experimental analysis. The objective of the study was to provide insights into the configuration factors influencing fire spread in cable trays. Through a series of controlled laboratory experiments, a set of cable tray configurations were analysed. Our results revealed critical issues influencing fire propagation and indicated like the number of cables per trays and the number of trays.

1. Introduction

Nuclear sector has performed an intense effort to increase knowledge in this topic. One of the most significant experimental campaigns in this regard was performed under the CHRISTIFIRE project [1]. Here NIST conducted 26 large-scale tests involving horizontal cable trays stacked vertically in a well-ventilated space. The tests varied the type of cables used and the arrangement of the cables. Subsequently, the results of this campaign were utilized to develop a simple model of upward fire spread in horizontal tray configurations, named FLASH-CAT model. Despite the comprehensive nature of the 26 tests, encompassing 17 different cables, 4 combinations of cable tray numbers, and 9 different numbers of cables per tray, results were primarily aimed to define a model applicable to various case scenarios rather than analyze the specific effects of individual variables on cable fire propagation. Broadly speaking, results showed more propagation with the large number of cables per tray, no propagation in the single tray case, and complete propagation in the tests with the four trays.

A further study [2] demonstrates that altering certain conditions of the cable trays, such as positioning them closer to support walls or doubling the fire power, results in the variation of dependent parameters like ignition time, fire growth rate, and heat release rate. Other experimental campaigns conducted at the iBMB OSKAR installations [3] [4] focused on analyzing the influence of the number of cable trays and the number of cables per tray. Unlike the findings of the CHRISTIFIRE study, these tests revealed that a larger number of cables per tray decreased fire propagation within the cable trays. Additional studies examining the effect of cable arrangements on the burning behavior of cable trays [5] showed that denser cable arrangements resulted in higher horizontal propagation. The CFSS campaign tests, PRISME Program, were carried out in an open room to facilitate complete ventilation of the experiments [6], thereby enabling the analysis of the influence of cable type on propagation. Similarly, the CFS test campaign, conducted as part of the PRISME 3 Program, examined the effects of sidewalls and cable arrangements in specific scenarios [7]. Notably, loosely configured cable arrangements exhibited higher fire propagation rates.

While these experimental campaigns have enhanced our understanding of the complex issue of fire propagation in cable trays, they also underscore the need for further research. The complexity of cable tray fire propagation phenomena and the multitude of independent variables that influence them can yield seemingly contradictory results, as evidenced by the varied findings on the influence of the number of cables per tray.

This paper presents the results of an exploratory experimental study on fire propagation in horizontal cable trays in an open atmosphere. The study aimed to represent various scenarios and evaluate the impact of configuration factors on the rate and extent of fire spread.

2. Methodology

The tests aimed to investigate the impact on fire propagation of (1) the number of cables per tray and (2) the number of cable trays. While the number of trays varies between 2 or 3, the number of cables per tray range in 12, 24 or 35 cables, as shown in Table 1.

Table 1. Description of independent variables.

Test	Trays nº	Cables per tray	Test	Trays nº	Cables per tray
E1	2	12	E3	3	35
E2		24	E4		12

An experimental set up was defined based on typical fire scenarios in nuclear plants, consisting in a 0.04 m² pool fire ignition source positioned below cable trays (see Figure 1). Its upper edge situated 0.15 m below the lower tray and a distance between the trays of 0.2 m. The ignition source utilized was a pool fire with a square section of 0.04 m², containing a mixture of 1 liter of kerosene and 50 cl of gasoline, resulting in an estimated fire power of 37 kW. Figures 2 to 5 show the disposition of the cables in the different experimental tests. It was considered a loose arrangement in the cable disposition, with gaps between cables that allow the flame to pass through. Although the cable tray is 30 cm wide, cables in tests E1 and E4 were distributed in less than 20 cm wide, and cables in tests E2 and E3 in 30 cm wide.

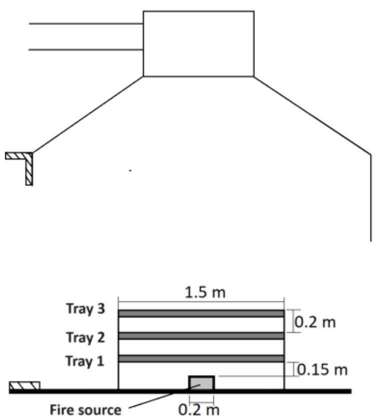

Figure 1. Front view of the test set-up.

Figure 2. Disposition of the Test E1.

Figure 3. Disposition of the Test E2.

Figure 4. Disposition of the Test E3.

Figure 5. Disposition of the Test E4.

The cables within the trays had a total length of 1.5 m. A cable with a Euroclass Eca rating and compliant with the non-flame propagation standard UNE-EN 60332-1- 2 has been selected for the study. The cable is identified as ENERGY Class RV-K FOC/FXV 0.6/1 kV 3G4 mm^2 (Figure 6). Cable consists of an outer sheath of polyvinyl chloride acrylic (PVC), insulation of cross-linked polyethylene (XLPE) and a cooper conductor. Table 2 presents the diameters of the cable, as well as the masses per unit length of the whole cable and of the combustible components of the cable.

Table 2. Geometrical data and mass per unit length of the cable.

External diam.(mm)	Insulator diam.(mm)	Copper diam.(mm)	Cable mass p.u.l. (kg/m)	Sheath mass p.u.l. (kg/m)	Insulation mass p.u.l. (kg/m)
10.7	3.8	2.3	0.196	0.082	0.020

Figure 6. Cable C1

Damaged length of cables from flame spread was monitored with two cameras, measuring visually the position of the front flame location in each side from ignition source axis. Then, a linear regression with the time evolutions enabled us to calculate the horizontal spread rate [2]. The spread rate considered is the maximum comparing left and right propagation. However, it is noteworthy that in certain cases, the propagation of the flame front does not reach the border of the cable trays, indicating that under these conditions, these cables undergo self-extinguishment. Additionally, a load cell was used to record mass variations during the tests. The HRR was measured by monitoring the depletion of oxygen within the hood.

3. Results

3.1 Influence of the number of cables

Table 3 provides information on the time to ignition, total affected length, and spread rate in scenarios with 12 and 24 cable per tray with two cable trays. The ignition times of the cable trays are lower for the case E1 with the lower number of cables per tray. First cable tray ignites almost half the time with half the cables per tray, 44 s versus 80 s. In E2, the flame front spread until the end of the cable trays, with a higher horizontal spread rate observed compared to E1 with half the number of cables, 2.1 times higher in the first tray and 2.6 times higher in the second tray. The total mass loss was 1.7 kg for E1 and 5.4 kg for E2, which suppose a 46.3 % and a 73.5 % of the total cable polymer mass, respectively.

Figure 7 illustrates the comparison of the HRR. The delay in ignition of the lower tray in the test with more cables, E2, is evident in the slower increment of the HRR curve. On the other hand, obviously the peak HRR value is higher in E2 due to the larger amount of combustible material, and the greater spread of the flame front. This extensive spread is correlated with the significant heat release observed during E2, facilitating fire propagation. The total heat release in E1 is 41.1 MJ, while in E2 it is 145.9 MJ. Consequently, considering the total mass consumption, the overall effective heat of combustion is calculated as 24.2 MJ/kg for E1 and 27.3 MJ/kg for E2.

Table 3. Ignition time, burned length and spread rate for the tests E1 and E2.

	Cables per tray	t_{ign} (s)	Burned length (m)	Spread rate. (mm/s)
E1	12	44-60	0.58-0.60	0.470-0.579
E2	24	80-180	1.28-1.39	1.40-2.10

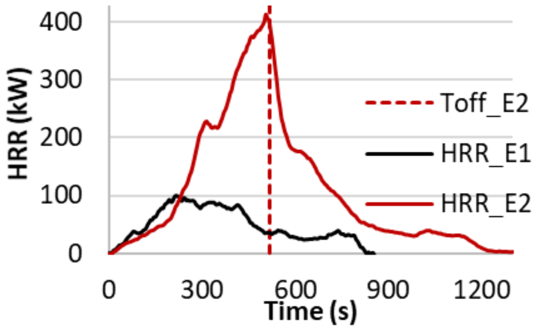

Figure 7. HRR from E1 and E2.

The influence of the number of cables in a scenario with three cable trays was also analysed. Table 4 presents the time to ignition, total affected length, and spread rate of each cable tray. Similar to the scenario with two cable trays, the time to ignition of the different cable trays is higher for the test with a larger number of cables, E3. In this case, the ignition time of the first tray of E3 is only 1.4 times higher than in case E4. During test E3, the flame front propagated close to the total length of the cable trays; however, it was extinguished prematurely due to safety concerns. Here as well, the horizontal spread rate is higher with a larger number of cables. Horizontal spread rates in case E3 are 1.5, 2.0 and 2.7 times higher than in case E4 for the first, second and third cable trays respectively. The total mass loss was 4.4 kg for E3 and 2.3 kg for E4, which suppose a 27.4 % and a 41.8 % of the total cable polymer mass, respectively.

The comparison of the HRR is shown in Figure 8. The peak HRR value is higher in E3 due to the larger amount of combustible material, consistent with the findings from the comparison of E1 and E2. The HRR peak has a value of 536.11 kW in E3 and 201.08 kW for E4. The total heat release in E3 is 123.8 MJ, while in E4 it is 67.5 MJ. Considering the total mass consumption, the overall heat of combustion is calculated as 28.45 MJ/kg for E3 and 29.33 MJ/kg for E4.

Table 4. Ignition time, burned length and spread rate for the tests E3 and E4.

	Cables x tray	t_{ign} (s)	Burned length (m)	Spread rate. (mm/s)
E3	35	65-138-186	0.91-1.1-1.14	0.88-1.42-1.76
E4	12	46-86-111	0.73-0.84-0.85	0.59-0.70-0.66

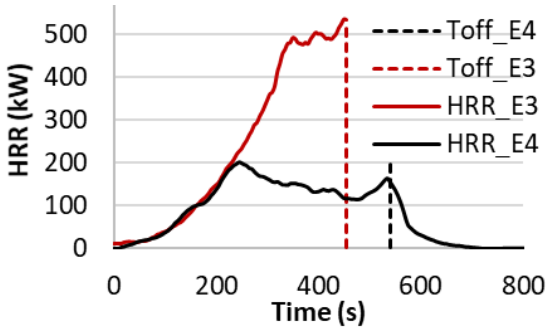

Figure 8. HRR from E3 and E4.

3.2 Influence of the number of trays

Table 5 presents information regarding the time to ignition, total affected length, and spread rate in scenarios with two and three cable trays. The ignition times of the lower tray are essentially the same in both tests. However, the ignition time is slightly higher in the second tray for the case with more cable trays, E4. The burner length was larger in the trays of E4, with more cable trays leading to a higher HRR, as depicted in Figure 9. This higher HRR facilitates propagation as it preheats the cables. This is consistent with the higher spread rates observed in E4 compared to E1. The total mass loss was 1.7 kg for E1 and 2.3 kg for E4. The total heat release in E1 is 41.1 MJ, while in E4 it is 67.5 MJ. Consequently, considering the total mass consumption, the overall heat of combustion is calculated as 24.19 MJ/kg for E1 and 29.33 MJ/kg for E4.

Table 5. Ignition time, burned length and spread rate for the different trays of tests E1 and E4.

	Nº of trays	t_{ign} (s)	Burned length (m)	Spread rate. (mm/s)
E1	2	44-60	0.58-0.60	0.470-0.579
E4	3	46-86-111	0.73-0.84-0.85	0.59-0.70-0.66

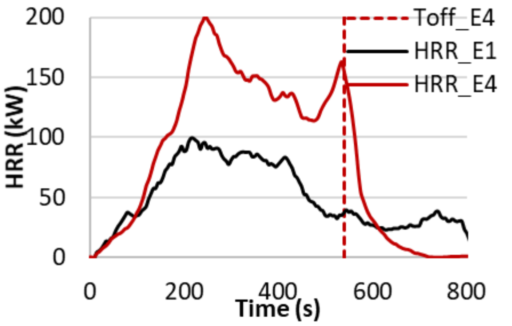

Figure 9. HRR from E1 and E4.

4. Discussions

This section summarizes a comparison of the E2 and E3 results presented in the paper with similar well-ventilated tests of the PRISME program. It should be borne in mind that all those tests allowed the flame propagation till the border of the tray.

Table 6 collects the comparison of the boundary conditions of the different cables tray tests. The PRISME campaign uses as ignition source a gas burner, while GIDAI-CSN campaign uses a pool fire. PRISME tests consider the cable trays close to a wall by a side. Cables are only classified as thermoplastic (TP) or thermoset (TS). It should be noted that cables in CFSS-2 are considered like TS due to the fire retardants contained.

Table 6. Comparison of the conditions of the different tests.

Campaign	Test	Trays nº	Cable	Cables per tray	Trays separation (m)	Burner (kW)	Burner-tray distance (m)
PRISME	CFSS-1	5	TP	49	0.3	80	0.2
	CFSS-2	5	TS	32	0.3	80	0.2
	CFSS-4	5	TP	44	0.3	80	0.2
GIDAI-CSN	E2	2	TP	24	0.2	37	0.15
	E3	3	TP	35	0.2	37	0.15

Table 7 includes the comparison of the time to ignition and horizontal spread rate for all cases. Although PRISME experimental tests considered two times HRR for the burner respecting our tests, which highly affect the ignition times, similarities are found between the PRISME and the GIDAI-CSN tests. GIDAI-CSN campaign shows that the horizontal spread rate increases for the upper cable trays, as occurs in the PRISME tests. PRISME experimental results in terms of spread rates are higher due to the higher ignition source HRR, but also to the large number of cables per tray.

Table 7. Comparison of the time to ignition and horizontal spread rate for the different tests.

Campaign	Test	Cable	Time to ignition (s)	Spread rate (mm/s)
PRISME	CFSS-1	TP	40 - 58 – 66- 72 - 86	3.0 -2.9-4.9-6.3-7.1
	CFSS-2	TS	264-396-603-741- 834	0.8 -1.1-2.7-3.0-6.4
	CFSS-4	TP	54 - 69 – 73-100- 123	2.8-2.7-2.9-5.1-5.9
GIDAI-CSN	E2	TP	80 -180	1.4-2.1
	E3	TP	65 -138 -186	0.9-1.4-1.8

5. Conclusions

The purpose of this exploratory campaign is to gain insights into the impact of the number of cables per trays and of the number of trays, on the rate and extent of fire spread. A total of 4 large-scale experimental tests were performed to analyze fire propagation in cable trays.

The experimental tests consistently demonstrated that increasing the number of cables per tray led to longer ignition times, but higher spread rates. The ignition times of the cable trays appear to depend on the number of cables, with longer ignition times observed when more cables are present. This relationship should be attributed to higher heat losses induced by the larger mass of fuel. Nevertheless, results also show that denser cable arrangements cause more intense and rapid propagation of fire within the trays. Additionally, tests with a higher number of cables per tray exhibited greater HRR and total heat release, indicating a higher combustion intensity. This observation underscores the importance of considering cable density as a critical factor in assessing fire hazards for these scenarios.

Comparisons with other experiments highlighted variations in ignition times and spread rates due to differences in experimental setups and conditions. Despite discrepancies, trends such as higher spread rates in the upper cable trays were consistent across different studies.

Although study deals with the influence of the number of cables per tray and the number of trays more experimental tests are required to completely characterize the influence of these parameters in the fire propagation. Additionally, repeatability tests are required to calibrate variability in the results associated with the tests repetition.

Acknowledge

The authors acknowledge the Nuclear Safety Council for the co-financing of the project "Metodologías avanzadas de análisis y simulación de escenarios de incendios en centrales nucleares" and for the research project SUBV-18/2022 “NUCLEVS - Validación, calibración y aplicación de modelos de propagación de incendios en escenarios reales de Centrales Nucleares. The authors also acknowledge RAPPID, Grant TED2021-132410B-I00 funded by MICIU/AEI/10.13039/501100011033 and by “European Union NextGenerationEU/PRTR.

References

[1] NUREG/CR 7010 Cable Heat Release, Ignition, and Spread in Tray Installations during Fire (CHRISTIFIRE): Phase 1 - Horizontal Trays, NIST, 2012.

[2] P. Zavaleta, R. Hanouzet, T. Beji, Improved Assessment of Fire Spread over Horizontal Cable Trays Supported by Video Fire Analysis, Fire Technology, 55, 233–255, 2019.

[3] M. Siemon, O. Riese, J. Zehfuß, Assessment of the burning behavior ofprotected and unprotected cables and cable trays in nuclear installa-tions using small and large-scale experiments, Proceedings of SMiRT 23, United Kingdom, 2015.

[4] M. Siemon, O. Riese, B. Forell, D. Krönung, W. Klein-Heßling, Experimental and numerical analysis of the influence of cable tray arrangements on the resulting mass loss rate and fire spreading, Fire and Materials, 43, 5, 497-513, 2019.

[5] X. Huang, H. Zhu, L. Peng, Z. Zheng, W. Zeng, K. Bi, C. Cheng, W. Chow, Burning behavior of cable tray located on a wall with different cable arrangements, Fire and Materials, 43, 2018.

[6] P. Zavaleta, S. Charbaut, G. Basso, L. Audouin, Multiple horizontal cable tray fire in open atmosphere, Thirteenth international conference of the Fire and Materials, USA, 2013.

[7] H. Pretrel, P. Zavaleta, S. Suard, Experimental investigation of the effects of a sidewall and cable arrangement on a horizontal cable tray fire in an open atmosphere, Fire and Materials, 2022.