CPR classification of cables and fire safety: contribution of innovative PVC and Halogen free compounds

AMI CABLES
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About IPOOL

IPOOL is R&D – Technology company, Spin-Off company of Italian National Council of Research institute (CNR), established on July 2011 in Pisa (ITALY).

IPOOL, working in international projects from Europe to Middle East, from Russia to Asia, from Northern to Southern America, is technical specialist in **cables**, **ACP composite panels**, **TPO/PVC/bitumen roofing** membranes, **pipes** and **rubbers**.

Main expertise:

- Flame retardant fillers for PVC and halogen free compounds
- Design and testing of new additives for compounds
- Cost and performances optimisation of PVC and HFFR compounds.
- Equipment for compounding: twin screw extruders, co-kneaders, internal mixers, …
- Optimization of extrusion of insulation and sheathing compounds
- Laboratory testing equipment for R&D and QC
- Selection and training of technical people for R&D activities (experimental thesis)
- Design of marketing strategy for new products and new additives

Main conclusions of IPOOL' speech at Cables 2021

- In real fire events, CO concentrations regularly exceed toxicity limit (LC_{50}), while those of HCl and HCN (coming from burning of materials containing chlorine and nitrogen) and that of acrolein (coming from burning of HFFR compounds) rarely exceed their LC_{50}. In other words, there is so much more CO than anything else in fire atmospheres that **CO is the big toxic killer in smoke**.

- **Acidity is totally inadequate as a representation of smoke toxicity**. The use of acidity as the basis on which to assess toxicity of fire effluents may provide an illusion of life safety which is, in fact, incorrect, since the most common toxicant (CO, carbon monoxide) is not acidic and not taken into account.

- **HFFR cable classified as $B2_{ca}$ d_0 s_1 a_1** and a **PVC cable classified as $B2_{ca}$ d_0 s_1 a_3** would guarantee **the same safety** in case of fire. But, at **today (=2021), no PVC cables classified as "s_1" have been certified** and proposed to market.

⇒ ***Not anymore!***

Executive summary

Collection of 100 meters of **5 flame retardant cables** with identical construction:

- 5 copper conductors insulated with silan XLPE (the most common insulation in cables), some flexible and some rigid (unfortunately)
- Bedding/filling compound in between insulated wires and sheathing (PVC and non-PVC)
- Outer sheathing/jacketing layer (PVC and non-PVC)

All cables:

- with as much as possible similar construction and geometry for reliable comparison.
- burned in CPR chamber and compared in terms of heat release and smoke/toxic gas release
- Commercial and developmental compounds used for the cables have been described, analysed and compared.

The FR cables

Code	Std CPR PVC	FRLS PVC	FRLS PVC4Cables	Std HFFR	Special HFFR
Cable	**FG16OR16 5*1.5**	**N2XH-0 5*1.5**	**FG16OR16 5*1.5**	**N2XH-0 5*1.5**	**N2XH-0 5*1.5**
outer Ø, mm	11,7	13	12-12,3	12,2	12,9
Thickness					
Sheathing, mm	1,57-1,92	1.39-1.71	1,89-2,15	1.35-1.6	2.05-2.29
Bedding (min-mean-max), mm	0,2-0,5-1,8	0,5-1,6-2,5	0,2-0,7-1,5	0,3-0,6-2,0	0,3-0,8-1,9
Insulation, mm	0,67-0,75	0,57-0.69	0,66-0,71	0,61-0.78	0,64-0,84
Mass distribution					
Sheathing, g/m	91,1	97,6	112	74,8	109,6
Bedding (min), g/m	31,5	63,1	22,6	60,2	35,6
Insulation, g/m	22,9	20,3	31	20,6	18,8
Picture					

Legend: FR=Flame retardant - **FRLS**=Flame retardant Low Smoke
HFFR=Halogen Free Flame Retardant (equivalent to **LSZH/LS0H** and **NHFR**)

Std FR PVC cable

Type: FG160R16 5x1,5
External diameter: 11,7 mm

	Sheathing	**Bedding**	**Insulation**
Producer / Supplier	Italian Company	Italian Company	European
Compound type	**FR PVC**	**FR PVC**	Silan XLPE
Thickness (mm)	1,57-1,92	0,2-0,5-1,8	0,67-0,75
Mass distribution (g/m)	91,1 (62,5%)	31,5 (21,5%)	22,9 (16%)
Density (g/cm^3)	1,61	1,96	0,92
Hardness Shore A 15 sec	90	92	-/>50 Sh D
LOI (%)	36	42	<18
Smoke emission ASTM E-662			
Smoke density (flaming)	340	-	-
Smoke density (not flaming)	324	-	-
HCl emission IEC 60754-2 [double measurement]			
pH	2,43 / 2,50	2,98 / 2,98	-
Conductivity (µS/mm)	130 / 133	40 / 46	-

FRLS PVC Cable

Type: N2XH-0 5x1,5
External diameter: 13,0 mm

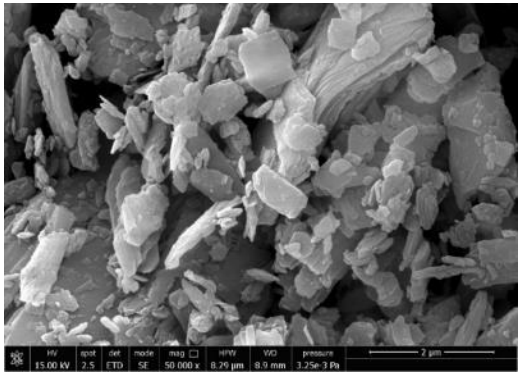
	Sheathing	Bedding	Insulation
Producer / Supplier	Ukraine Company	Ukraine Company	European
Compound type	**Non-toxic FRLS PVC**	**Non-toxic FRLS PVC**	Silan XLPE
Thickness (mm)	1,39-1,71	0,5-1,6-2,5	0,57-0,69
Mass distribution (g/m)	97,6 (54%)	63,1 (35%)	20,3 (11%)
Density (g/cm^3)	1,66	1,85	0,92
Hardness Shore A 15 sec	91	91	-/>50 Sh D
LOI (%)	35	28	<18
Smoke emission ASTM E-662			
Smoke density (flaming)	151	75	-
Smoke density (not flaming)	133	70	-
HCl emission IEC 60754-2			
pH	2,85	3,40	5,82
Conductivity (µS/mm)	53	15	0,8

FRLS PVC4Cables

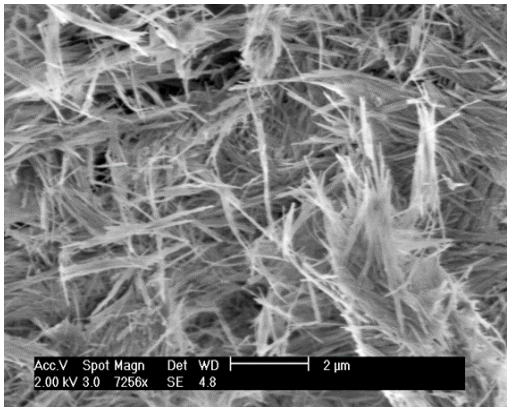
Type: FG16OR16 5x1,5
External diameter: 12,2

	Sheathing	Bedding	Insulation
Producer / Supplier	FRLS PVC4cables	FRLS PVC4cables	European
Compound type	FR LS low acidity PVC	FR LS low acidity PVC	Silan XLPE
Thickness (mm)	1,89-2,15	0,2-0,7-1,5	0,66-0,71
Mass distribution (g/m)	112 (67,5%)	22,6 (13,5%)	31 (19%)
Density (g/cm^3)	1,80	1,92	0,92
Hardness Shore A 15 sec	85	90	-/>50 Sh D
LOI (%)	36	40	<18
Smoke emission ASTM E-662			
Smoke density (flaming)	69	-	-
Smoke density (not flaming)	121	-	-
HCl emission IEC 60754-2 [double measurement]			
pH	3,60 / 3,66	3,94 / 3,61	-
Conductivity (µS/mm)	6,4 / 8,9	5,68 / 11,9	-

Reduction of Smoke density of FR PVC compounds



- Reduction of ATO and increase of **Zinc Borate**
- Increase of total filler content (up to 90phr for sheathing), especially with hydrated FR like **natural milled MDH** (up to 50phr for sheathing) which reduce smoke density by releasing water during combustion: *FR, smoke suppressant and acid scavenger at once*.
- Use high surface calcium carbonate, like fine pp synthetic $CaCO_3$



- Replacement of volatile aromatic plasticisers (like DOTP) by **low volatility plasticisers**, better if aliphatic (not aromatic), and even better if **alkyl phosphate** type.
- Addition of **specific synergistic additives** like one-pack MBS 207/15 by Reagens and engineered nano silicate Adins Clay 80T by Tolsa.
- Addition of **Molybdenum** and **Tin compounds** (MoO_3, AOM, $ZnSn(OH)_6$ very efficient FR and smoke suppressant, used in *special* applications like *plenum cables* in USA.

Standard HFFR cable

Type: N2XH-0 5x1,5
External diameter: 12,2 mm

	Sheathing	Bedding	Insulation
Producer / Supplier	Ukraine Company	Ukraine Company	European
Compound type	medium LOI std HFFR	medium LOI std HFFR	Silan XLPE
Thickness (mm)	1,35-1,6	0,3-0,6-2,0	0,61-0,78
Mass distribution (g/m)	74,8 (48%)	60,2 (39%)	20,6 (13%)
Density (g/cm^3)	1,48	1,89	0,92
Hardness Shore A / Shore D	>92 / 53	92 / -	-/>50 Sh D
LOI (%)	32	35	<18
Smoke emission ASTM E-662			
Smoke density (flaming)	22	-	-
Smoke density (not flaming)	205	-	-
HCl emission IEC 60754-2			
pH	5,84	5,82	-
Conductivity (µS/mm)	0,5	0,8	-

Special HFFR cable

Type: N2XH-0 5x1,5
External diameter: 12,9 mm

	Sheating	Bedding	Insulation
Producer / Supplier	Ukraine Company	Ukraine Company	European
Compound type	High LOI special HFFR	High LOI special HFFR	Silan XLPE
Thickness (mm)	2,05-2,29	0,3-0,8-1,9	0,64-0,84
Mass distribution (g/m)	109,6 (67%)	35,6 (22%)	18,8 (11%)
Density (g/cm^3)	1,55	1,93	0,92
Hardness Shore A / Shore D	>92 / 55	92 -	-/>50 Sh D
LOI (%)	43	85	<18
Smoke emission ASTM E-662			
Smoke density (flaming)	12	-	-
Smoke density (not flaming)	145	-	-
HCl emission IEC 60754-2			
pH [Prom. / PVC4C]	6,21	5,81	-
Conductivity (µS/mm)	0,5	0,8	-

Traditional HFFR compound for sheathing of cables

Component	%	Notes
EVA18 + EVA28	18-22	Polar, flexible polyolefin
C_2-C_8 Plastomer	4 - 8	Non polar, flexible polymer
mLLDPE	4 - 8	Non polar, rigid polymer
Coupling agent		
LLDPE-g-MAH	4 - 5	Maleated coupling agent
Fillers (total=62-65%)		
Main FR filler	40-60	Fine precipitate ATH
2nd FR filler	5-15	Stearic coated n-MDH d_{50}=3.5 μm
3rd filler	0-15	Stearic coated $CaCO_3$ d_{50}=1.5 μm
Additives		
Silicon masterbatch	1 – 1,5	External lubricant
Hydrophobic agent	0,25 - 0,5	Silan masterbatch in pellets
Stabilizer	0,25 - 0,5	Blend of stabilizers/antioxidants

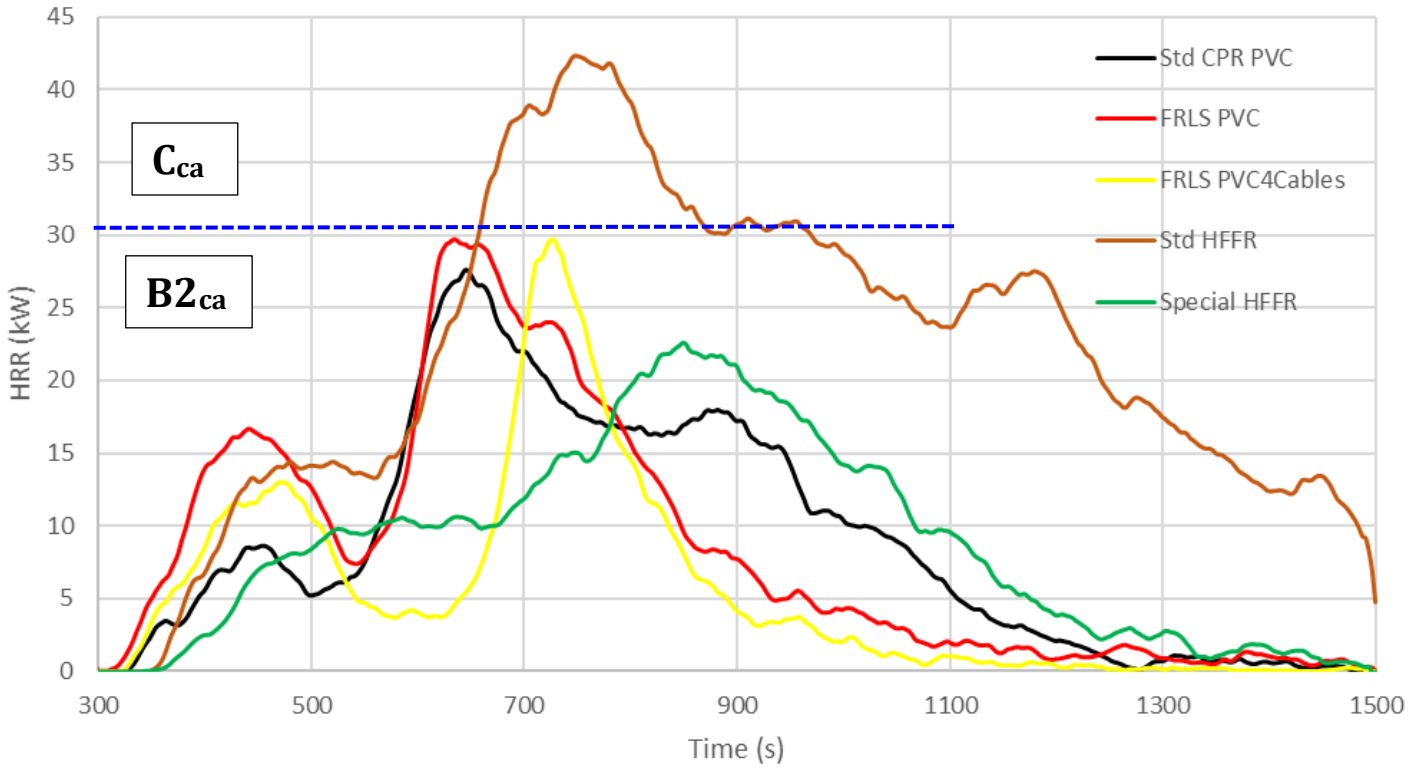
⇒ ***Best performances in fire test are with n-MDH and without $CaCO_3$***

Results of EN 50399 - CPR class EN 13501-6

Code	Std FR PVC	FRLS PVC	FRLS PVC4cables	Std HFFR	Special HFFR
CPR EN 50399					
Number of samples	13	12	12	12	12
FS, m	**1,06**	**1,07**	**1,00**	**1,95**	**0,77**
Burning droplets	none	none	none	none	none
Peak HRR, kW	**27,6**	**29,8**	**29,9**	**42,3**	**22,6**
THR 1200s, MJ	10,7	10,1	6,6	26	10,5
Peak SPR, m^2/sec	0,85	0,26	0,12	0,08	0,05
TSP 1200s, m^2	278,4	75,2	37,3	43,7	22,7
FIGRA, W/s	80,3	139,7	92,9	97,3	45,7
Classification	**$B2_{ca}$ d_0 s_2**	**$B2_{ca}$ d_0 s_2**	**$B2_{ca}$ d_0 s_1**	**C_{ca} d_0 s_1**	**$B2_{ca}$ d_0 s_1**

FS=Fire spread (length of burned part) **HRR**=Heat of Release Rate
THR=Total Heat Release **SPR**=Smoke Production Rate **TSP**=Total Smoke Production

FR(LS) PVC vs HFFR compounds: Heat Release Rate evolution of cables

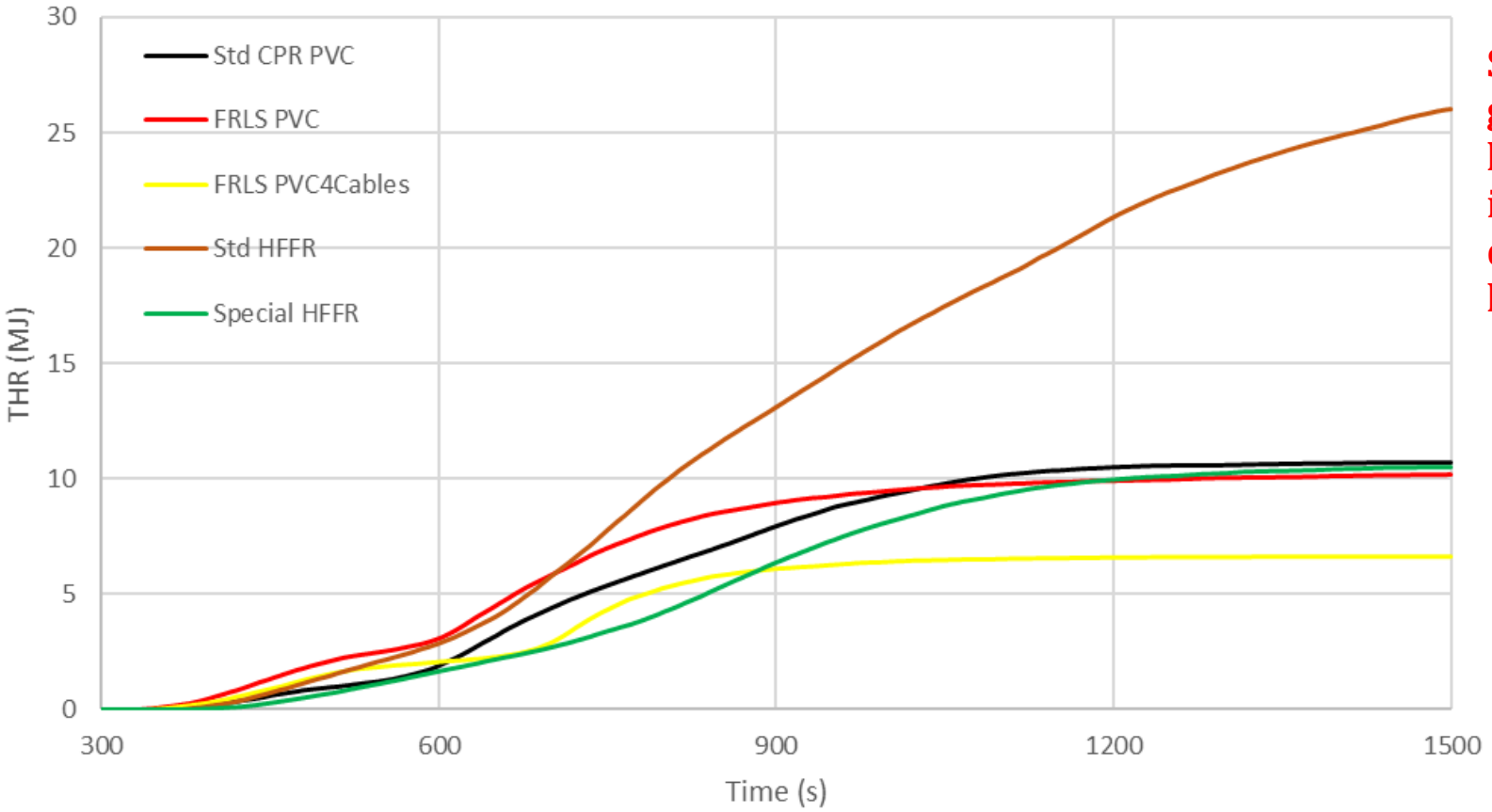


Cable	Fs (m)
FR PVC	1.06
FRLS PVC	1.07
FRLS PVC4cables	1.00
Std HFFR	1.95
Special HFFR	0.77

⇒ FR PVC cables and special HFFR cable give similar heat release and FS=Fire spread

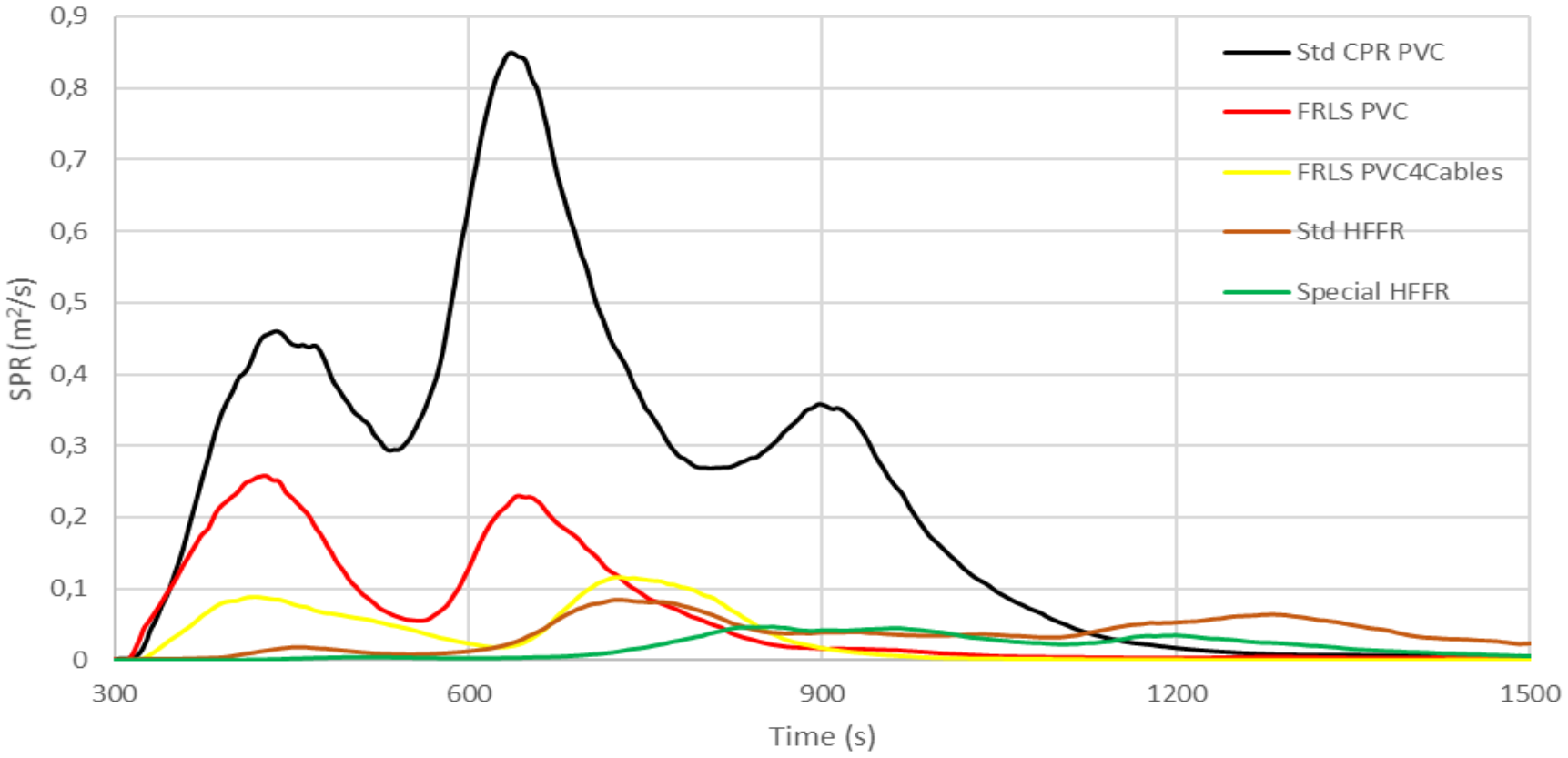
⇒ Std HFFR cable showed significantly higher heat release and fire spread

FR(LS) PVC vs HFFR compounds: Total Heat Release evolution



Std HFFR cable gives significantly higher fire spread in case of fire event due to much higher heat release

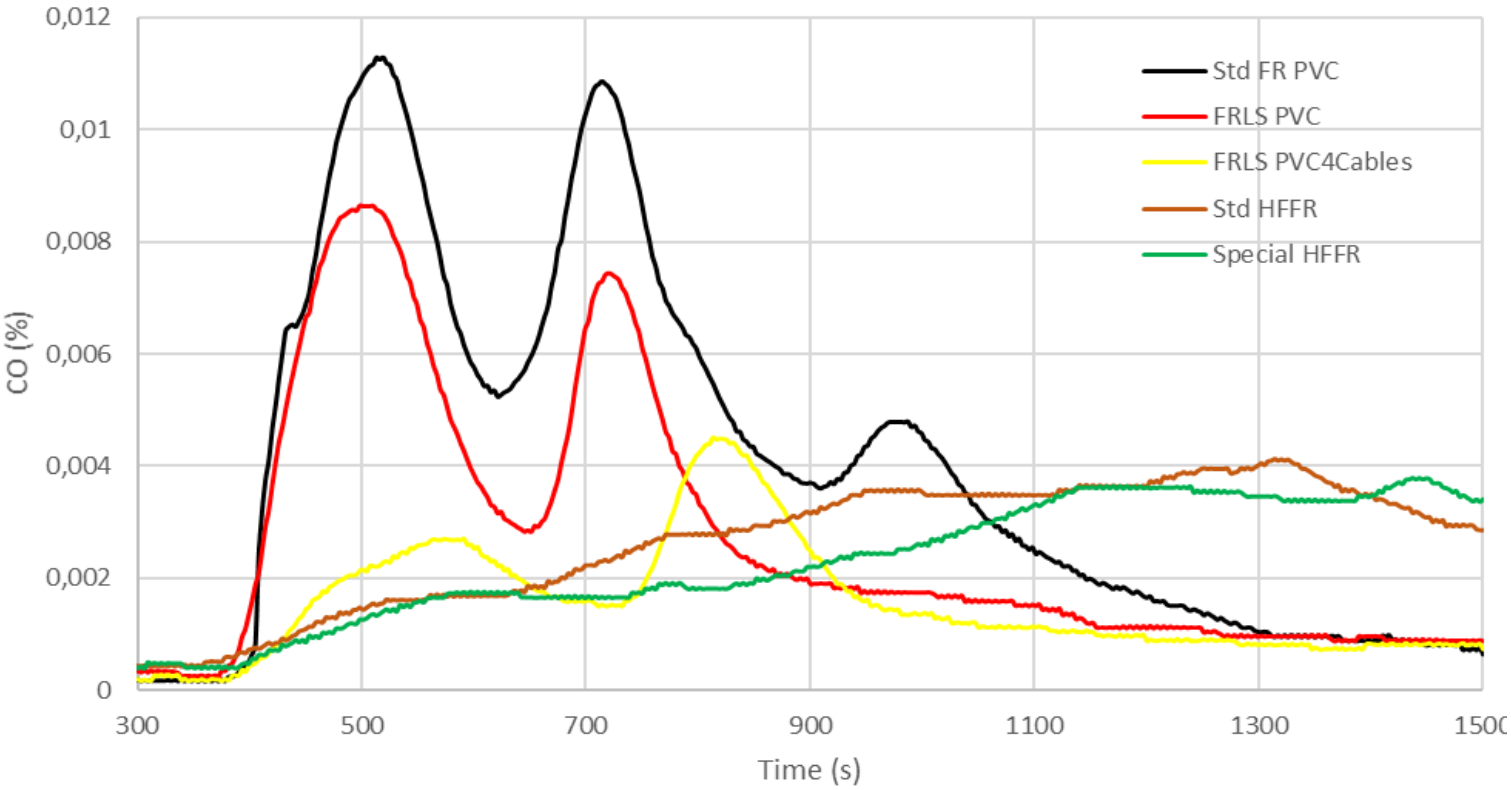
Smoke Production Rate evolution



⇒ HFFR cables produce very low smokes, independently on the composition

⇒ PVC cables show very different emission of smokes depending on formulation

FR(LS) PVC vs HFFR compounds: CO evolution



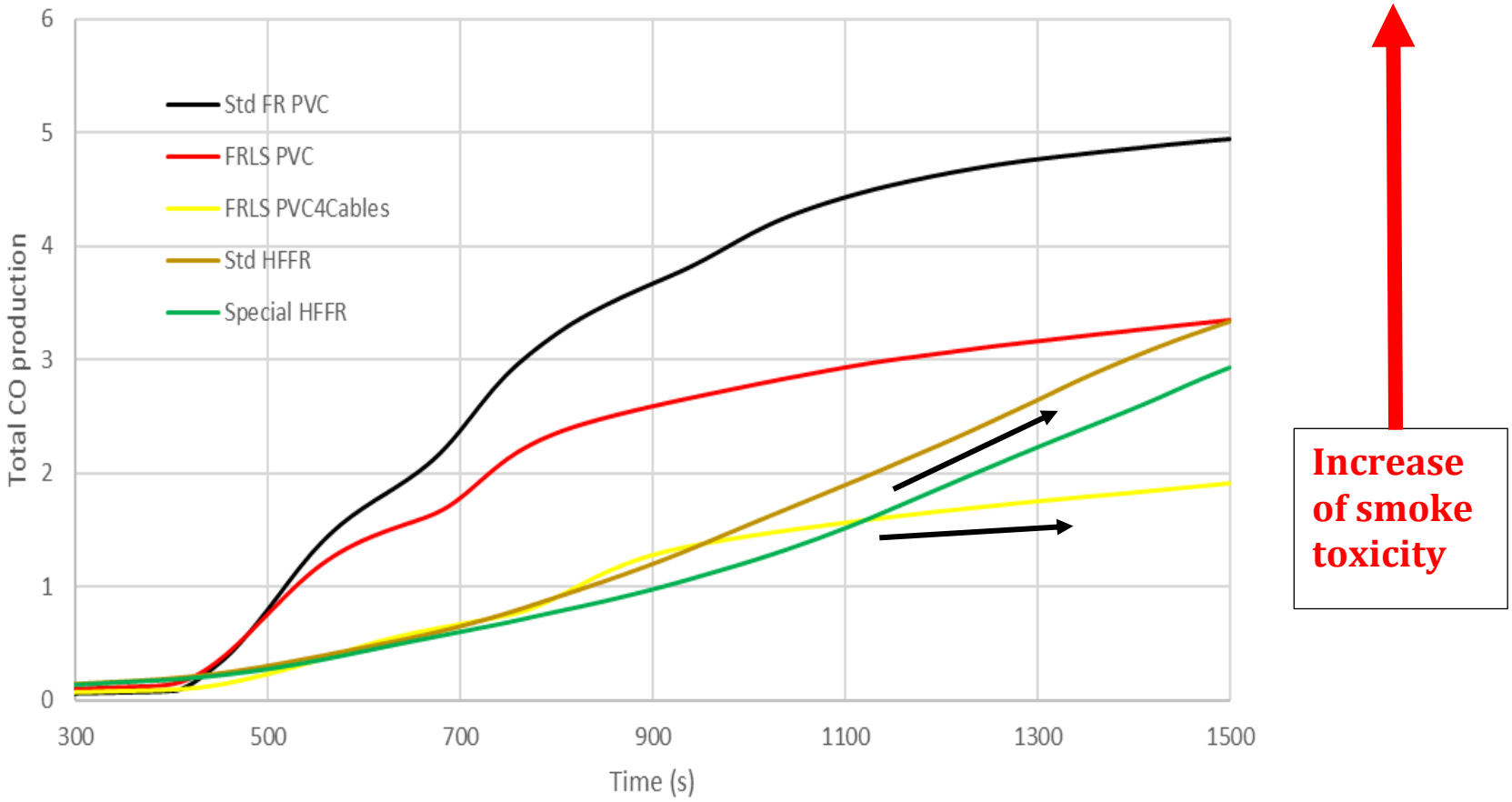
Emission of CO is faster and higher for FR PVC, and lower for FR LS PVC which have low CO emission like HFFR cables.
HFFR cables release more CO in the 2nd half of the burning test.

⇒ Emission of CO is the most relevant parameter of smoke toxicity

⇒ CO emission from PVC and from HFFR compounds follows different kinetics

⇒ The formulation has bigger influence into CO emission for PVC than for HFFR compounds

FR(LS) PVC vs HFFR compounds: total CO Production evolution



⇒ *Cumulative CO emission for PVC and HFFR cables confirms different kinetic*

Smoke emission test on sheathing compounds: ASTM E662

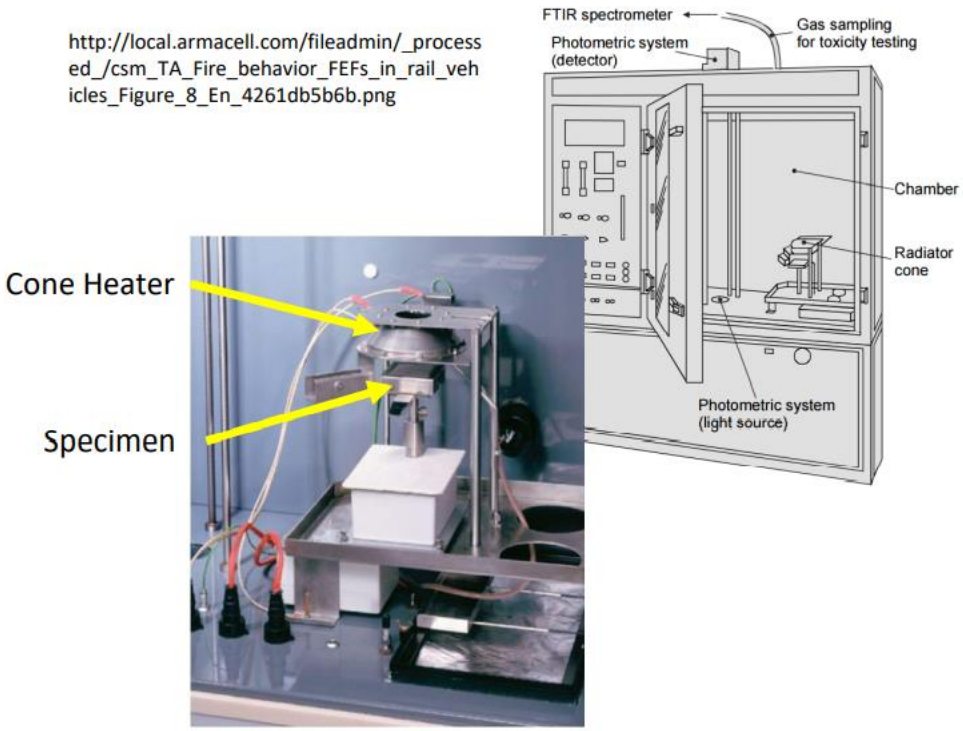
Results	Std FR PVC	FRLS PVC	FRLS PVC4Cables	Std HFFR	Special HFFR
Flaming	340	151	69	22	12
Not Flaming	324	133	121	205	145

Test condition:

- Radiation applied: 25 kW/m²;
- Test conditions: with and without flame;
- Samples size: 75 x 75 mm;
- Distance between sample surface
  And radiation source: 25 mm.

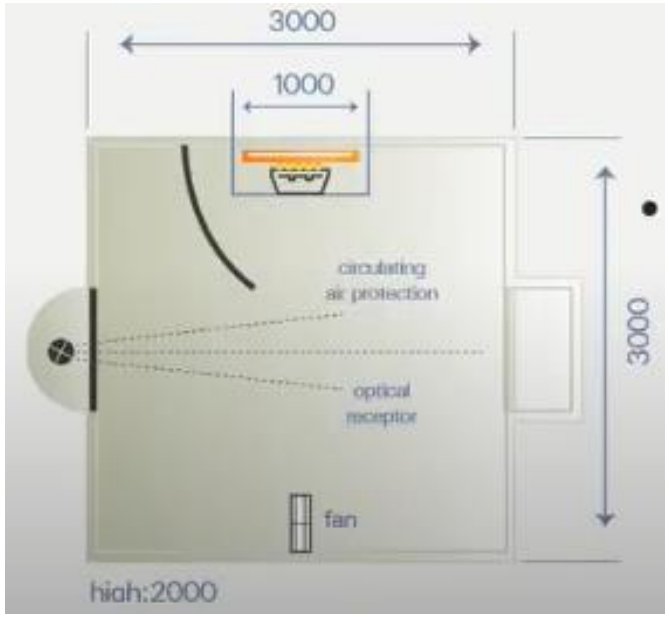
Values relatively close to numbers obtained on CPR EN 50399 burning test.

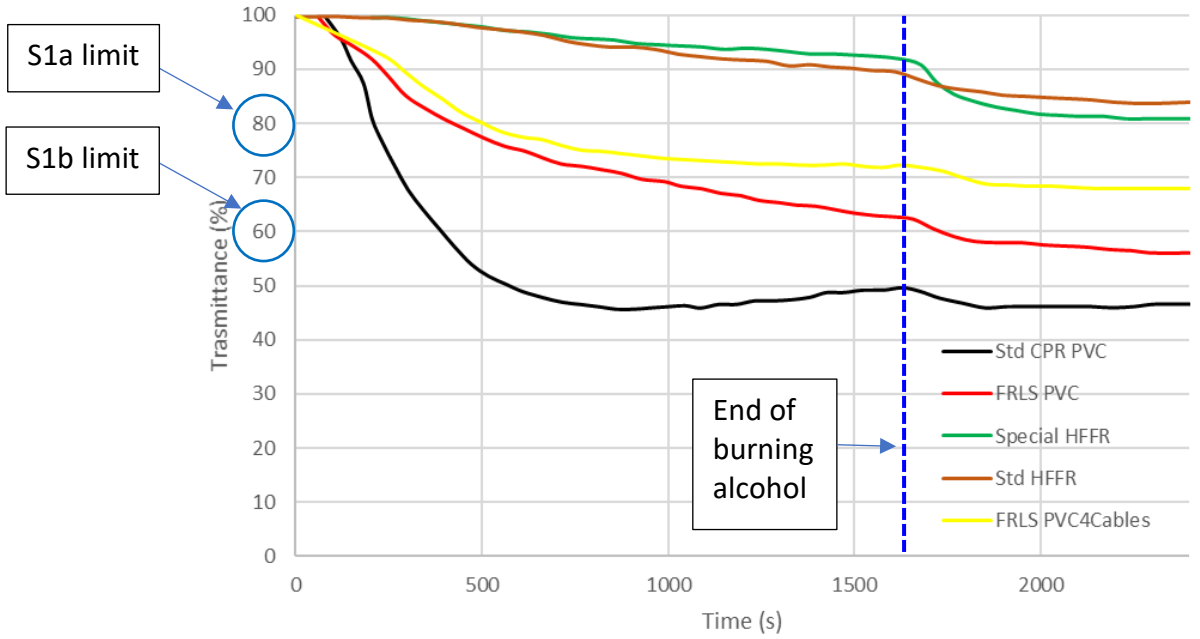
http://local.armacell.com/fileadmin/_processed_/csm_TA_Fire_behavior_FEFs_in_rail_vehicles_Figure_8_En_4261db5b6b.png



Smoke emission test on cable: IEC 61034-2

Results	Std FR PVC	FRLS PVC	FRLS PVC4Cables	Std HFFR	Special HFFR
Residual transmittance, %	45,7	55,9	67,9	84	80,6
Number of samples	3	3	3	3	3





Comparison between different smoke release test done on cables and sheathing

Results	Std FR PVC	FRLS PVC	FRLS PVC4Cables	Std HFFR	Special HFFR
ASTM E662 (on compound)					
Flaming	340	151	69	22	12
Not Flaming	324	133	**121**	**205**	145
IEC 61034-2 (on cable)					
Residual transmittance, %	45,7	55,9	67,9	84,0	80,6
Smoke density, %	54,3	44,1	32,1	16,0	19,4
CPR EN 50399 (on cable)					
Peak SPR, m^2/sec	0,85	0,26	0,12	0,08	0,05
TSP 1200s, m^2	278,4	75,2	37,3	43,7	22,7

CPR Smoke Classification	**s_2**	**s_2**	**s_{1b}**	**s_{1a}**	**s_{1a}**

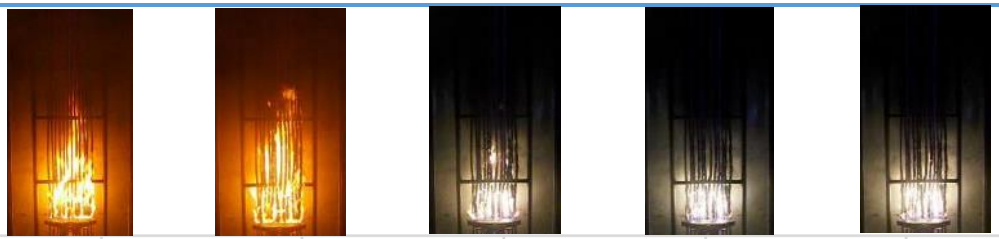
CPR EN 50399 criteria

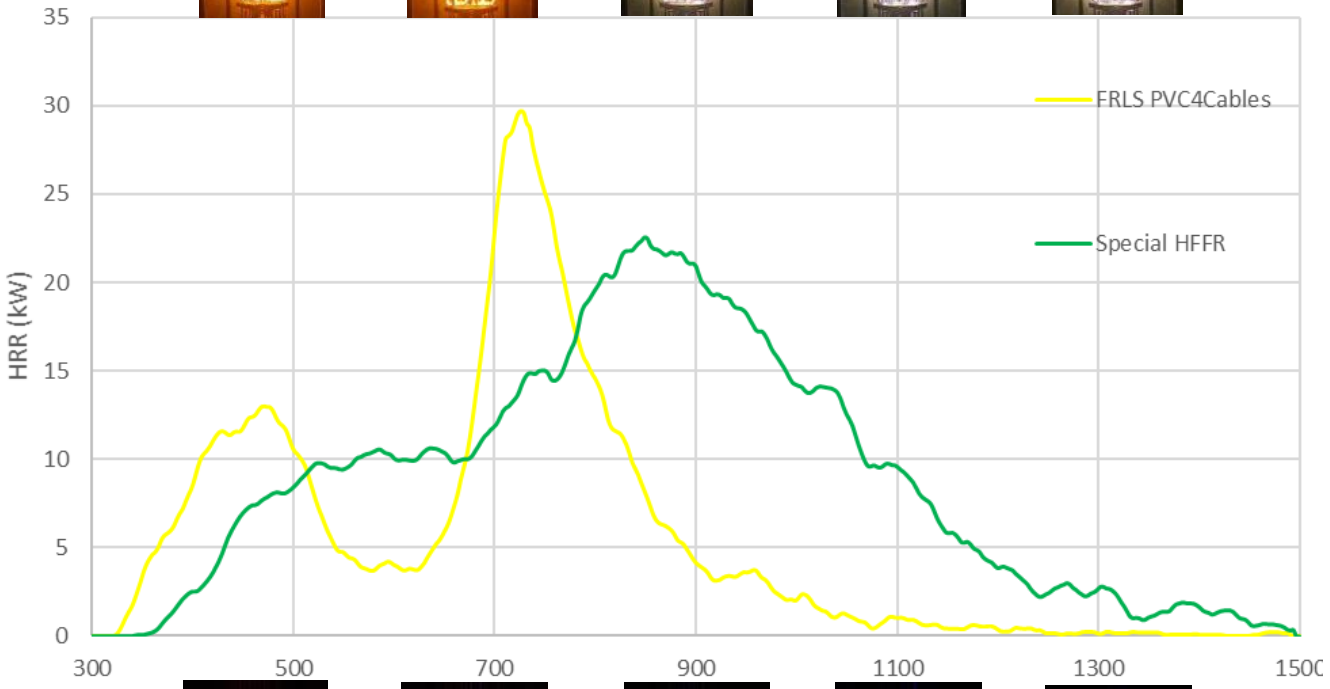
Peak SPR, m2/sec	≤0,25 (s_1)	≤1,5 (s_2)	>1,5 (s_3)
TSP 1200s, m2	≤50 (s_1)	≤400 (s_2)	>400 (s_3)

From IEC 61034-2 criteria

Transmittance	60% <T ≤80% (s_{1b})	>80% (s_{1a})

Special HFFR

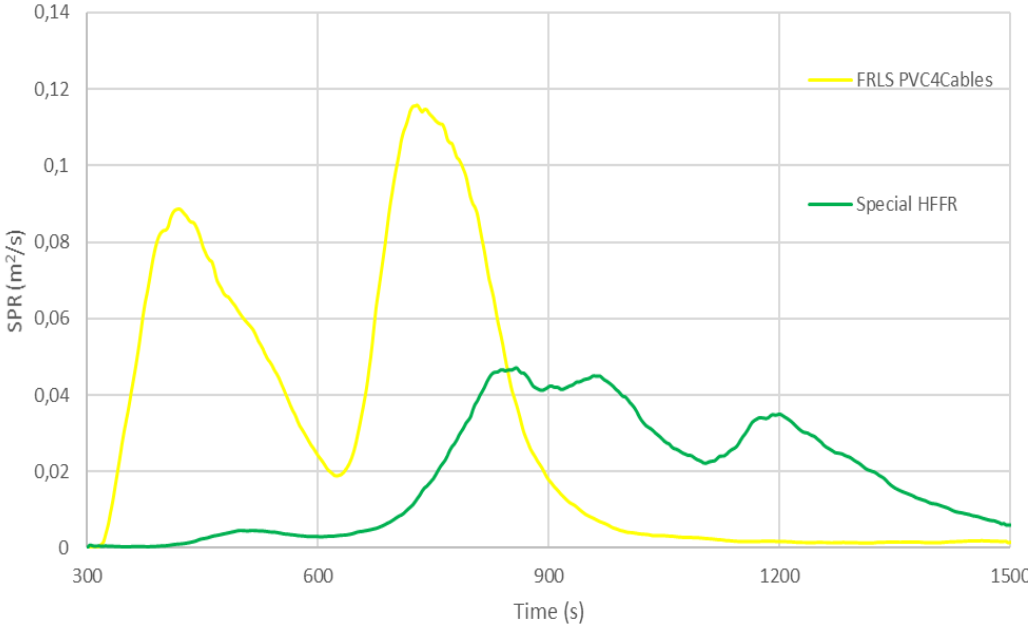




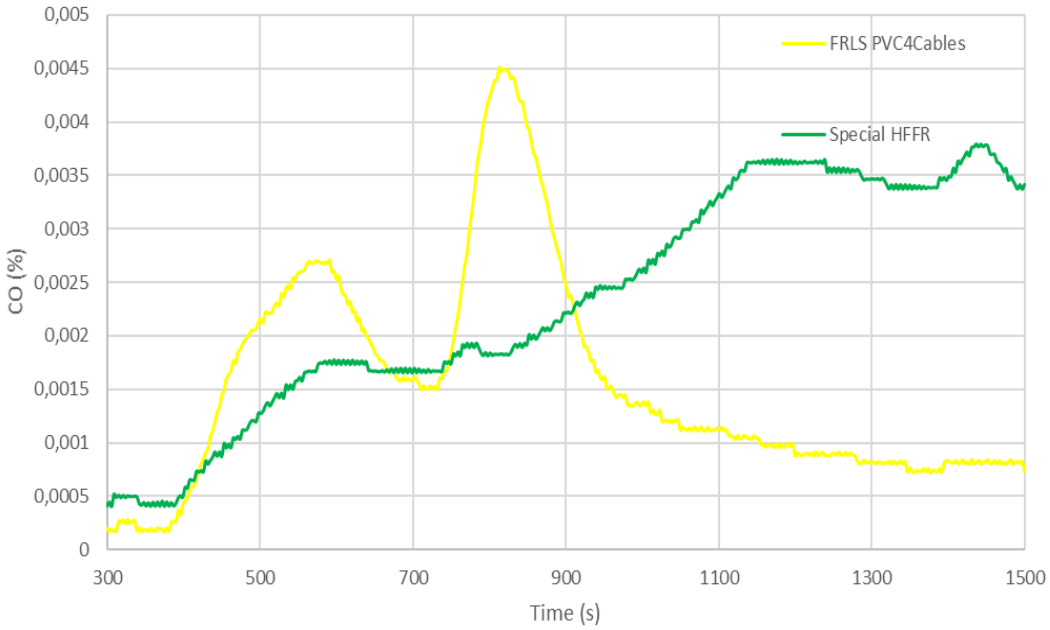
FRLS PVC4Cables

FRLS PVC4Cables ($B2_{ca}$ d_0 s_{1b} a_3) and Special HFFR ($B2_{ca}$ d_0 s_{1a} a_1)

Smoke production



CO emission



⇒ Both very safe cables

Challenges for PVC compounds vs HFFR compounds

Code	Self-ignition T (°C)	Heat of combustion MJ/kg	LOI (%)	Flame spread	Tendency to drip	Smoke release
EVA/POE/LLDPE	320 - 350	40-45	<20	High	Medium/high	Medium
PVC	450	<20	42	Low	No	High
Plasticized PVC	250-300	25-30	23	Low	No	High

Multiple actions necessary:

- Removal of traditional ingredients producing high smokes
- Introduce new classes of plasticisers with less negative impact on flame retardancy
- Increase content of minerals acting as flame retardant, HCl scavenger and smoke suppressant
- Replace low and medium chain chloroparaffins

...but without losing the traditional advantages of PVC:

- High speed of production
- Low formulation cost

Challenges for HFFR compounds

- Shortage of traditional polymers like EVA with 28% vinyl acetate
- High price of fine precipitated MDH (pp-MDH) and fine precipitated ATH (pp-ATH)
- Increase compounding output and cable extrusion speed (especially for “CPR” grades)
- Severe issues for **cracking** of jackets in harsh environment
- Very high competition and reduction of margins in thermoplastic HFFR compounds

Multiple actions are possible:

- Replacing EVA/LLDPE with balanced mixture of POE/LLDPE (Low MFI and flexible POE)
- Increase of n-MDH to compensate the reduction of flame retardancy
- Reduce maleated coupling agent to reduce viscosity (POE/LLDPE blends need less coupling)
- Replacing $CaCO_3$ with charring / antidripping additives like nano-additives (pure or MB)
- Higher content of hydrophobic additives due to higher n-MDH content
- Higher content of silicon MB (external lubricant)
- Viscospeed® (internal lubricant, in powder) to improve dispersion and reduce viscosity

Case Study: from traditional to EVA-free HFFR compound

Traditional EVA-based	%
EVA28/LLDPE	31
Fine Precipitated ATH	48
Natural milled MDH	12
LLDPE-g-MAH	4,5
Stearic Coated $CaCO_3$	3
Silmaprocess AL1142A	1
Silmastab AX2244	0,25
Silmastab AE1527E	0,25
TOTAL	100

EVA-free	%
POE/LLDPE	27,75
Fine Precipitated ATH	48
Natural milled MDH	**16**
LLDPE-g-MAH	**3**
Silmaflame AX2565	**3**
Silmaprocess AL1142A	**1,5**
Silmastab AX2244	**0,5**
Silmastab AE1527E	0,25
TOTAL	100

⇒ EVA-free compound shows higher crack-resistance, superior electrical properties, higher Temperature-rate and competitive cost

Comments and conclusions

- Regular FR PVC cable using cost competitive combination of sheathing and bedding compounds reached the classification **$B2_{ca}$ d_0** (even with highly flammable silan XLPE insulation) and **s_2** (medium smoke emission).

- Regular HFFR compounds gave cable with classification **C_{ca} d_0** with medium LOI values sheathing and bedding. With special HFFR compounds (both sheathing and bedding), classification improves to **$B2_{ca}$ d_0**. In both cases, **s_{1a}**

- Innovative PVC4cables compounds gave an excellent final cable in terms of low smokes (**B_{ca} d_0 s_{1b}**) and also emission of the killer gas CO. Reduction of smoke density is closely correlated with low CO production. In other words: **Low smokes = Low CO emission = Low Toxicity** (at least in these systems)

- Emission of CO from FRLS PVC cables during burning is fast and immediate, and almost zero after in the 2nd half of test; on the opposite, HFFR cables release CO more gradually, almost linearly during the fire test with higher release at the end of the test.

- Very good cables in terms of safety (=low smokes, low HRR, low CO emission, no dripping, low flame spread) are the result of competition between **special PVC compounds** (**$B2_{ca}$ d_0 s_{1b} a_3**) and **special HFFR compounds** (**$B2_{ca}$ d_0 s_{1a} a_1**). Letter "a" is not related to toxicity or safety of the cable, but just to differentiate HF from PVC.

Thanks to all suppliers of raw materials:

www.altairchimica.com/ producer of chloroparaffins and new chlorinated BIO plasticizers

www.italmatch.com, producer of special phosphorous-based flame retardant for polypropylene, polyurethane, HFFR and PVC compounds.

www.silmaster.com, producer of special masterbatches for HFFR compounds (Silmaprocess, Silmastab,)

www.europiren.com, producer of high quality, high purity, fine milled, natural magnesium hydroxide.

www.tolsa.com, producer of inorganic antidripping and ceramifying FR synergist for HFFR and PVC compounds

www.innospec.com, producer of special polar waxes (Viscospeed) and polymers

Thank you for the kind attention!

Special thanks for support to:

PROMINVEST
Cable compounds production