Smoke Density VS Heat Release: Two measurements, Two distinct fire hazards

This edition breaks down how to evaluate a fire testing lab beyond the obvious — focusing on the factors that truly influence safety, performance, and reliability.

FIRE SAFETY INSIGHTS 2026
SMOKE DENSITY VS HEAT RELEASE
KEY DIFFERENCES

TECHNICAL EDITION

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Featured Story

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WHY BOTH TESTS EXIST

TWO TESTS. TWO HAZARDS. ONE STANDARD.

Walk into any accredited fire testing laboratory and you will find two instruments at the heart of railway material compliance: the cone calorimeter and the smoke density chamber. They sit side by side, run back-to-back, yet measure fundamentally different phenomena.

Heat release rate tells you how fast a material feeds a growing fire. Smoke density tells you how quickly its combustion products will blind and incapacitate the people trying to escape. EN 45545-2 demands both — because a material that burns slowly but produces a dense, toxic smoke cloud is no less dangerous than one that ignites violently.

This editorial unpacks the science, instrumentation, metrics, and compliance implications of these two tests — and explains why Prospec engineers insist that no rail project can treat them as interchangeable or redundant.

In this Edition

K E Y I N S I G H T

A material can pass heat release tests yet fail on smoke density and vice versa. Both parameters are independently mandatory at every EN 45545 hazard level. There is no trade-off.

WHY BOTH TESTS EXIST

SCALE AND SCOPE

Why Fire Standards Cannot Choose Just One

Fire kills in two distinct ways. Thefirst isthermal — flames, radiant heat, and hot gases that cause burns and structural failure. The second is toxicological — smoke that reduces visibility to zero, poisons the respiratory system with CO and HCN, and incapacitates passengers long before flames reach them. Each pathway demands its own test.

Heat release rate quantifies the thermal pathway. The cone calorimeter measures how fast a specimen releases energy — and that rate directly determines how quickly a compartment reaches flashover. Smoke density quantifies the optical and toxicological pathway. The NBS smoke chamber measures how rapidly combustion products accumulate to the point where evacuation becomes impossible.

EN 45545-2 mandates both because they are genuinely independent. A material with low HRR may still produce extremely dense smoke. One with low smoke production may still release heat rapidly enough to cause flashover. Pass marks on both tests are non-negotiable at every hazard level.

DSMAX

SMOKE DENSITY LIMIT

Maximum specific optical density at 4 min for EN 45545 HL3 (ISO 5659-2)

FIGRAW/S

FIRE GROWTH RATE

Key HRR metric from cone calorimeter — ≤300 W/s required at HL3

600
SEC

THR WINDOW

Total heat release is integrated over the first 600 seconds (THR600s)

25
kW/m²

TEST IRRADIANCE

Standard heat flux used in both smoke chamber and cone calorimeter

TWO TESTS — WHAT EACH CATCHES

- **Cone Calorimeter: High heat release, rapid flashover risk, materials that burn intensely but may produce thin smoke**
- **Smoke Chamber:Dense smoke, reduced visibility, smouldering materials that seem 'safe' on HRR but are toxic.**
- **FTIR Coupled:CO, HCN, HCl — toxic gas species that drive CITg, invisible in both HRR and optical density alone.**
- **LateralFlame Spread:How quickly fire travels across a surface — relevant to floor coverings (R4) under EN 45545-2**

HEAT RELEASE RATE DEEP DRIVE

HEAT RELEASE

The Cone Calorimeter: What it Measures and Why it Matters.

Heatrelease rate (HRR) is, by broad consensus in the fire science community, the single most important variable in fire hazard characterisation. Expressed in kilowatts per square metre (kW/m2), HRR quantifies the rate at which a burning material releases thermal energy into its surroundings. Peak HRR determines how quickly a compartment transitions through the stages of fire development — incipient, growth, flashover — while total heat release governs duration and severity.

The cone calorimeter (ISO 5660-1) is the instrument through which EN 45545-2 measures HRR for railway materials. A 100 mm x 100 mm specimen is mounted horizontally or vertically depending on the material application, conditioned to standard humidity, and irradiated at a defined heat flux — typically 25 kW/m2 for surface materials and 50 kW/m2 for high-performance engineered components. The instrument measures oxygen consumption in the exhaust stream: because combustion consumes oxygen in a predictable ratio to energy release, this indirect calorimetry method delivers HRR curves of high precision and repeatability.

EN 45545-2 does not specify a simple peak HRR limit. Instead it uses two derived parameters that capture both the rate and the trajectory of heat release. FIGRA — the Fire Growth Rate Index — is calculated as the peak value of the ratio of HRR to time (W/s) and captures how explosively a material contributes to early fire growth. THR600s is the total heat released in the first 600 seconds (MJ) and represents the total thermal energy burden a burning material imposes on its compartment.

At HL3 — the most demanding hazard level, applied to tunnel and underground operations — FIGRA must not exceed 300 W/s and THR600s must not exceed 10 MJ. Compare this to HL2 limits of 750 W/s and 15 MJ respectively: the HL3 thresholds are designed specifically for scenarios where flashover in the first ten minutes of a fire could trap hundreds of passengers in a tunnel with no immediate escape route.

CONE CALORIMETER KEY METRICS

Metric	HL2 Limit
FIGRA(W/s)	≤ 750
THR600s (MJ)	≤15
Peak HRR (kW/m^2)	Informative
CO/CO■ ratio	Recorded
Time to ignition	Recorded

Representative values; see EN 45545-2 Annex C for R-set specifics

TEST OUTPUTS PER RUN

- Time-to-ignition (TTI) in seconds
- HRR curve over full test duration
- Peak HRR and FIGRA calculation
- THR600s — total heat in first 600 s
- Smoke production rate (SPR)
- CO and CO■ concentrations
- Mass loss rate of specimen

> ***"FIGRA is not just a compliance number — it is a proxy for how many seconds you have before the fire in one seat becomes a compartment-wide inferno. At HL3, that margin is razor-thin."***

SMOKE DENSITY DEEP DRIVE

SMOKE DENSITY

The NBS Smoke Chamber: Seeing What the Cone Calorimeter Cannot

Smoke is the leading cause of incapacitation and death in railway fire incidents — notflame. Occupants who cannot see theexit, cannot read emergency signage, and cannot breathewithout incapacitation are trapped regardless of how slowly or quickly the material is burning. This is thehazard that the smoke density chamber (NBS smoke box, ISO 5659-2) is designed to quantify.

The test apparatus is deceptively simple in concept: a 75 mm x 75 mm specimen is positioned in a sealed chamber of 0.51 m3 and exposed to a radiant heat flux of 25 kW/m2. Two conditions are run — with and without a pilot flame — because smouldering and flaming combustion can produce dramatically different smoke yields. A photomultiplier system measures the transmission of a light beam across the chamber continuously throughout the test, generating a curve of specific optical density (Ds) against time.

The compliance metric extracted from this curve for EN 45545-2 purposes is VOF4 — the integral of Ds over the first four minutes of the test, expressed in m2/kg·min. This integration is deliberate: it captures not just peak smoke density but the rate of smoke accumulation during the critical early phase of a fire, when evacuation decisions are being made and conditions are transitioning from tolerable to lethal. A material that produces a sudden dense smoke spike at two minutes is more dangerous than one that produces the same total smoke over ten minutes — and VOF4 captures this distinction.

At HL3, VOF4 must not exceed 150 m2/kg·min. At HL2, the limit relaxes to 300 m2/kg·min. Materials that smoulder — rubbers, certain foams, cable jacketing — often produce their most dangerous smoke in the non-flaming condition, which is why both pilot flame conditions must be reported and the worst case used for compliance determination.

> *"A material can smoulder quietly — low heat release, no visible flame — while filling an enclosed carriage with smoke dense enough to render evacuation impossible within two minutes."*

SMOKE CHAMBER KEY METRICS

Metric	HL2 Limit	HL3 Limit
VOF4 (m²/kg·min)	≤ 300	≤ 150
Ds at 4 min	Informative	Informative
Max Ds (flaming)	Recorded	Recorded
Max Ds (non-flaming)	Recorded	Recorded
Ds@1min, 2min, 4min	Full curve	Full curve

Representative values; see EN 45545-2 Annex C for R-set specifics

WHAT ISO 5659-2 PRODUCES

- Specific optical density (Ds) vs time curve
- VOF4 — integrated Ds over 4 minutes
- Flaming and non-flaming conditions separately
- Peak Ds and time of peak smoke accumulation
- Light transmittance % throughout test
- Mass loss of specimen (for yield calculations)
- Input data for FTIR toxicity coupling

SIDE BY SIDE COMPARISION

FOCUS AND STRATERGY

Why HRR and Smoke Density Agree- and Where they Don’t

The most common misconception among procurement engineers encountering fire testing for the first time is that heat release and smoke density move together — that a material producing less heat will also produce less smoke. This is wrong, and the consequences of that assumption have caused compliance failures on major rollingstock programmes. Phenolic composites are an instructive example. They are the material of choice for HL3-rated railway interiors precisely because they exhibit low FIGRA and low THR600s — but they can produce relatively high smoke optical densities during early flaming. An engineer specifying phenolics solely on the basis of their heat release performance may be surprised to find a smoke density test failure. The solution is to formulate with smoke-suppressant additives or to select grades specifically optimised for dual compliance.
Polyurethane foam presents the opposite problem. Standard furniture-grade PU foam can produce moderate Ds values — smoke that, while present, does not immediately saturate the chamber.

DUAL-COMPLIANCE MATERIAL STRATEGIES

Halogen-free phenolic composites with zinc borate smoke suppressant — best dual
performer for structural panels
Graphite-intumescent FR PU foam —
achieves
80%+ FIGRAreductionwhilemaintaining acceptable VOF4
HFLS (halogen-free low-smoke) cable sheaths— mandatory at HL3, eliminates HCl and dense smoke risk
Aramid/modacrylic fibre blends for
upholstery
— inherently low in both HRR contribution and
smoke yield
ATH/MDH mineral fillers in polymer matrices — endothermic cooling reduces both heat release and smoke density
Intumescent coatings on steel structures
—
seal off combustible substrates, reducing both test parameters

But its HRR curve is catastrophic: peak HRR values that generate FIGRA well above 750 W/s and THR600s that dwarf HL2 limits. The fire-modified FR foams used in railway seating specifically target FIGRA and THR600s reduction — often achieving 80% FIGRA reduction — while the smoke suppressant chemistry must be tuned separately.

MATERIAL BEHAVIOUR MATRIX — HEAT RELEASE vs SMOKE DENSITY

Material	HRR Risk	Smoke Risk	Strategy
Phenolic	Low ✓	Medium ▲	Add smoke suppressant
composite	High ✗	Medium ▲	Switch to FR-modified
Standard PU foam	Low ✓	Low ✓	grade Verify CITg
FR PU foam	Low ✓	High ✗	separately Replace with
PVDF cable	Medium ▲	Medium ▲	HFLS grade Use
sheath GRP/epoxy	Low ✓	Low ✓	intumescent FR resin
panels Wool-			Preferred HL3 upholstery
aramid fabric			

WHEN MATERIALS CONFLICT

Some FR additives that reduce HRR can increase smoke density by changing combustion chemistry. Halogenated retardants (bromine/chlorine) are the classic example — they are highly effective at suppressing flaming but produce HCl, HBr, and dense opaque smoke. EN 45545 HL3's CITg limit effectively bans them. Always test the final formulation — not the base polymer alone.

PEOPLE · EXPERTISE · PURPOSE

PRECISION

Combined Data Tells Us

At Prospec Labs , we run EN 45545-2 conecalorimeter and ISO5659-2 smoke density tests back-to-back on the same specimen batch—conditioning, mounting, and reporting underconsistent documented protocols. This is not simply a logistical convenience. Running both tests on the same material batch eliminates inter-batch variability as a confounding factor, giving clients the most accurate picture of how their actual production material performs on both parameters simultaneously.

Our FTIR system is coupled to the cone calorimeter exhaust, enabling us to report CITg alongside HRR and smoke data in the same test run. This means clients receive a single, comprehensive test report covering FIGRA, THR600s, VOF4, and CITg — the four parameters that together determine EN 45545-2 hazard level compliance — from a single test session. For programmes with complex material matrices, this is significant: it can reduce the total testing time and cost for a full interior qualification programme by 30–40% compared to sequential single-parameter testing.

We frequently encounter materials that pass heat release testing with comfortable margin and fail on VOF4, or vice versa. In every such case, our engineering team provides a formulation consultation — not just a test report. We identify which specific component of the material system is driving the failure, recommend targeted additive or reformulation strategies, and re-test to confirm compliance before the client commits to volume production. This is the Prospec service model: not a testing house, but a technical partner.

PROSPEC'S DUAL-TEST PROTOCOL

Specimen Prep
Singlebatchconditionedto23°C/50%RH—same specimensruninbothinstrumentsforzerobatch-to-batch variance

Cone Calorimeter
ISO5660-1at25or50kW/m2.FullHRRcurve,FIGRA, THR600s,peakHRR,CO/CO2,SPR.FTIRcoupled.

Smoke Chamber
ISO 5659-2at25kW/m2.Bothflamingandnon-flaming.Full Ds curve. VOF4andpeakDsreported.

Toxicity
CITgcalculated fromFTIRdata.HCN,HCl,HF,SO2,NOx quantified against HL3limits.

Report

Singleintegrated report covering all EN 45545-2 parameters — accepted by ERA notified bodies.

Consultation
Failureanalysisand reformulation guidance provided as standard. Re-test scheduling within 5 working days.

CERTIFER-RECOGNISED · ISO/IEC 17025 ACCREDITED

Reports accepted by European notified bodies.
India-based testing with global recognition.

"Both tests are mandatory. Both are independently pass/fail.
A result that passes one and fails the other is not 'nearly compliant'. It is a failed material. We help clients understand that distinction before it becomes an expensive re-engineering programme."

— Prospec Test Hub, EN 45545-2 Compliance Team

Partner with Prospec Labs to ensure your materials don’t just pass tests — they perform when it matters most.

PROSPEC'S APPROACH

LOOKING AHEAD

Same Standard. Same Material. Two Tests. Two Chances to Fail.

The fire safety case for a railway interior is only as strong as its weakest test result. EN 45545-2 does not offer compensatory scoring — a material that achieves outstanding FIGRA performance cannot 'offset' a VOF4 failure. Both parameters must pass independently, at the specified hazard level, for the material to be qualified for use.

As the railway industry pushes toward lighter, more sustainable interiors — bio-based polymers, recycled-content composites, thinner laminates — the challenge of achieving dual compliance on both HRR and smoke density becomes more, not less, complex. Many bio-based materials that are attractive from a sustainability perspective exhibit inherently higher smoke yields than the engineering polymers they replace. The R&D effort required to close that gap is substantial, and it begins with understanding precisely what each test measures and why. Prospec Labs is at the forefront of this challenge in the Indian market.

Our accredited laboratory, our FTIR-coupled cone calorimeter suite, and our experienced engineering team are available to support material qualification from initial concept screening through to final type test reporting. We test to EN 45545-2, IS 15614, and a range of international standards — and we issue Certifer-recognised reports that travel with your material through European regulatory processes.

The difference between smoke density and heat release is not academic. It is the difference between a material that passes and one that fails — and ultimately, between passengers who evacuate safely and those who do not.

8 THINGS EVERY RAIL ENGINEER MUST KNOW

1. HRR and smoke density are independent — a pass on one never guarantees a pass on the other
2. FIGRA captures fire growth speed; THR600s captures total thermal energy over 600 seconds
3. VOF4 integrates smoke optical density over 4 minutes — the critical early evacuation window
4. At HL3: FIGRA ≤ 300 W/s, THR600s ≤ 10 MJ, VOF4 ≤ 150 m²/kg·min — all must pass
5. Smouldering materials may pass HRR tests but fail smoke density — test both conditions
6. Halogenated FR additives are banned at HL3 — they suppress HRR but drive CITg failures
7. Assembly testing is mandatory — individual material results do not predict system performance
8. Prospec provides both tests, FTIR toxicity, and a single integrated EN 45545-2 report

Partner with Prospec Labs to ensure your materials don't just pass tests — they perform when it matters most.