THE ROOF COMES FIRST · WHITEPAPER

From risk models to design requirements

Translating risk models into PV roof design requirements

CORE THESIS (AUTHOR'S CONCLUSION)

For PV installed above combustible roof construction, the roof-PV design should include a consequence-limiting asset-protection baseline that interrupts the physical fire pathway into the building, alongside probability-reducing controls that act upstream of ignition. Baseline describes a design requirement, not the chronological order in which controls act during an incident.

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Prepared for asset owners, architects, roofing professionals, risk engineers, insurers and PV stakeholders.

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Author’s perspective

This series is a synthesis of published research, fire tests, standards, approvals and insurer guidance on fire safety and rooftop PV, written from an explicit roof-first perspective: I look at the complete commercial roof system and the building beneath it rather than at individual product classifications. Within that perspective I summarise what the evidence shows, add my own technical analysis and, where relevant, propose design principles. Those proposals are marked as mine and kept separate from what has been demonstrated.

My background is in architecture and building engineering. Over the past three years I have discussed this subject with engineers, risk specialists, insurers and test institutes, and I have been involved in setting up and supervising fire-test programmes for AllShield's own roof systems. That experience shapes the questions I ask; the papers test those questions against external evidence. How the sources were selected, and what remains open, is described at the end of each paper.

These papers are prepared by Olivier Langejan as lead author with support from a small team. His own professional focus is building and roof design; specialist findings are drawn from the cited evidence, with AI assistance disclosed separately in Method and sources.
I am affiliated with AllShield, which develops BarrierSheet and other roof fire-protection solutions. That commercial relationship is relevant and is therefore stated explicitly. The analysis does not assume that an AllShield product provides the effects discussed. The starting point is the physical or economic problem. Where an AllShield product is discussed, it is treated as one product-specific example and its performance should be read only within the boundaries of the cited tests, approvals and roof assemblies.

In this paper I use established fire-safety and risk-engineering frameworks to examine one specific question: once ignition prevention can no longer guarantee that a fire will not occur, what function should the roof itself perform? The objective is not to make the models point towards a particular product, but to test whether different analytical approaches lead to a consistent product-neutral design requirement.

Olivier Langejan | AllShield

Executive summary

Commercial rooftop PV should be treated as part of the building-and-roof system rather than as an electrical installation sitting above an unrelated roof. Fire is one of the clearest examples of why this matters. FM research shows that the presence of PV can change flame geometry and increase both radiative and convective heat transfer to the roof. The same research states that quality products, better design, installation and maintenance can reduce ignition likelihood but cannot eliminate it. Robust fire testing of the combined roof-PV assembly therefore remains necessary. [1]

The May 2024 ZAG/FRISSBE Fire Safety Guideline reaches a closely related conclusion. It treats PV fire risk as a combination of probability and consequence and emphasises system-level assessment. For consequence limitation, ZAG identifies non-combustible insulation as its primary recommendation. Where other solutions are considered, it states that they should demonstrate similar robustness in tests of the complete roof segment and PV modules at a scale that includes several modules. [2]

In this whitepaper I apply five established fire-safety and risk-engineering frameworks to one specific scenario: PV installed above combustible roof construction. The models do not prescribe AllShield BarrierSheet or any other product. Instead, they are used to test whether different analytical methods support the same product-neutral design priority.

In my application, five frameworks converge on the same asset-protection principle: do not leave an uninterrupted physical fire path from the PV fire into the building.

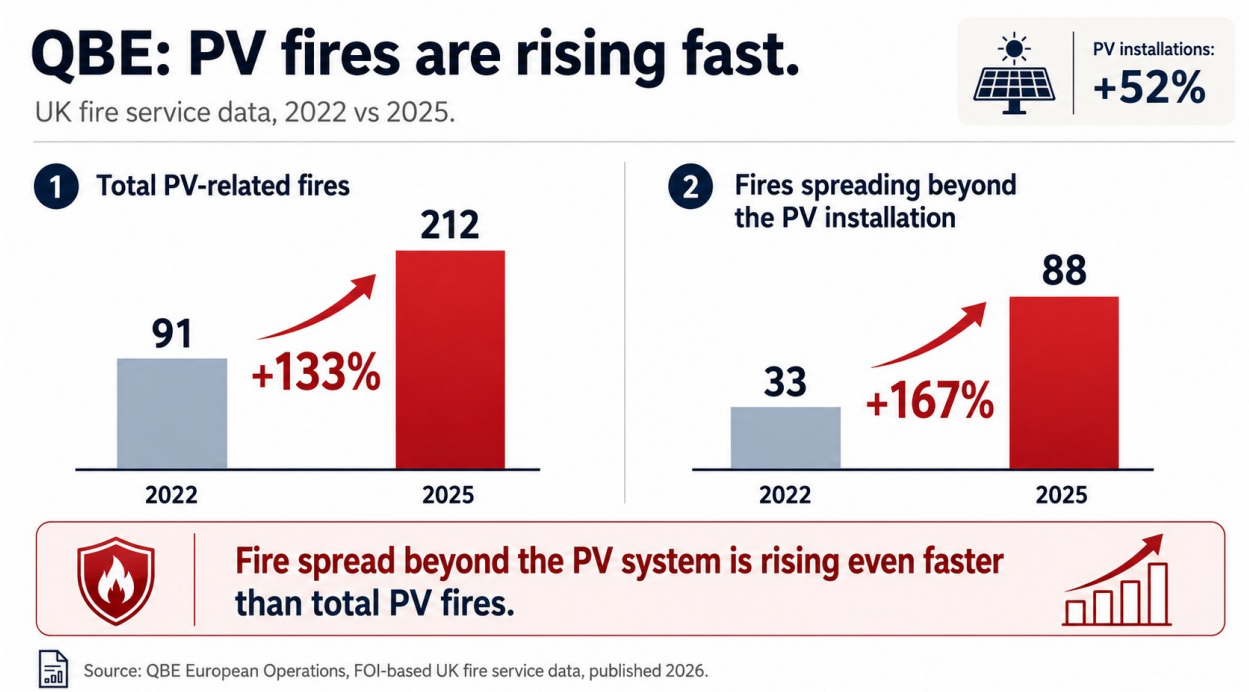
Framework	Risk function	PV roof implication
NFPA 550	Manage the impact	Ignition prevention is not the complete fire-safety strategy.
Bow-tie	Protect the consequence side	Place barriers after the Top Event as well as before it.
Event Tree	Interrupt the escalation	Create a safe stopping point before a roof fire becomes an internal building fire.
Fault Tree	Break the causal pathway	Remove or interrupt a necessary condition: the downward propagation path.
Defense in Depth	Establish the baseline	Combine preventive controls with passive protection that performs a different safety function.

The design conclusion I draw is deliberately risk-led rather than product-led. Where a fully non-combustible roof build-up is practical, it is a way to reduce the combustible fuel available in the roof escalation pathway. Where existing lightweight roofs cannot reasonably be rebuilt in that way because of structural reserve, disruption or economics, an alternative consequence-limiting strategy should be demonstrated through robust whole-system testing. A tested non-combustible separation layer directly beneath the roof membrane is one such strategy.

Rooftop PV is often approached primarily as an energy project. On commercial buildings, however, feasibility is frequently determined by the roof itself: structural capacity, roof build-up, remaining or intended service life, fire behaviour, fixing strategy and insurability. The order in which these questions are assessed matters. In this paper I focus on one of those gating questions, fire consequence, and use risk models to translate it into a design requirement before a product is selected.

1. Why the design question matters

The installed base of commercial rooftop PV is growing while incident data shows that the fire risk is not theoretical. In August 2026 QBE European Operations reported 212 UK solar-panel-related fires in 2025 compared with 91 in 2022. More importantly for asset protection, fires reported as spreading beyond the solar installation increased from 33 to 88 over the same period. QBE recommends avoiding combustible roofs or ensuring appropriate separation and fire-resistant barriers. [3]



This fire question should not be isolated from the broader roof decision. Whether the project concerns an existing roof or a new roof that can still be designed from the start, structural capacity, roof build-up, service life, fixing strategy and insurability can all govern whether rooftop PV is feasible. Fire consequence is therefore one gating condition within a wider roof-first assessment, not a standalone product question.

Figure 1. Recent QBE data illustrates the distinction between incident frequency and escalation beyond the PV installation.

From a building-design perspective, the distinction is straightforward. Preventive measures act mainly on the likelihood of ignition. Consequence-limiting measures act on what happens after ignition. Both matter but they perform different safety functions.

> **RISK EQUATION**
>
> **Risk is commonly conceptualised as the combination of likelihood and consequence. Reducing likelihood is valuable but a severe consequence can justify direct consequence-limiting measures even when the initiating event is uncommon.**

This matters particularly for warehouses, factories and distribution centres where a fire entering the building can create losses far beyond the PV installation and the building itself: structural damage, inventory loss, production interruption, supply-chain disruption and long recovery times.

2. What current fire research says about roof-PV systems

A central premise of my analysis is that the PV array and the roof below it should not be assessed as independent fire-safety questions. FM research describes how PV panels can alter the flame from a more vertical or wind-tilted shape into a flame constrained closer to the roof surface. This can increase radiative and convective heat transfer to the roof. Heated PV panels can also radiate energy back towards the roof and combustible panel components can add fuel. [1]

FM also makes the prevention limitation explicit: better products, design, installation and maintenance reduce ignition likelihood but do not eliminate it. Its research therefore treats robust fire testing of the combined roof construction and PV assembly as necessary to address large-loss potential. FM 4478 was developed to evaluate the roof and PV module assembly under a wind-driven fire exposure rather than testing the two as unrelated components. [1]

ZAG takes the same system view in its May 2024 Fire Safety Guideline for Building Applied Photovoltaic Systems on Flat Roofs. The guideline states that PV can increase both the probability and the consequences of roof fire and that the real risk emerges from the interaction of components. It recommends system-level fire-safety assessment rather than relying only on individual product classifications. [2]

> **ZAG GUIDELINE CONCLUSION**
>
> **For consequence limitation, ZAG identifies non-combustible insulation as the primary recommendation. If other solutions are considered, ZAG says they should demonstrate similar robustness in experiments on the complete roof segment and PV system at a scale that includes several modules. [2]**

This gives the risk discussion an important hierarchy. For new construction, using non-combustible insulation and minimising combustible content in the roof build-up is a route that reduces the combustible fuel in the roof build-up where it is structurally, technically and economically practical. Existing lightweight industrial roofs create a different problem. Structural load can be as decisive as fire performance: full replacement of combustible insulation with a substantially heavier non-combustible insulation build-up can consume limited roof reserve, compete with the load allowance required for PV or trigger costly structural strengthening. A lightweight consequence-limiting assembly may therefore be the more realistic engineering route, provided its performance is demonstrated at system level. In those cases the correct question is not whether a thin barrier is “the same as” non-combustible insulation. The question is whether an alternative assembly can demonstrate the required consequence-limiting function under representative system-level fire exposure.

Structural capacity is a finite design budget. Every kilogram allocated to the roof build-up, fire-protection strategy or mounting system reduces the capacity available for PV or may trigger structural reinforcement. Structural feasibility should therefore be established before the technical route is optimised.

Illustrative load comparison. Published roof-system data give U = 0.18 W/m²K for a 120 mm PIR assembly and a 200 mm mineral-wool assembly. The latter uses a stated density of 120 kg/m³, giving 24 kg/m² for the insulation alone. [18] These are alternative insulation routes. A thin protective layer over retained PIR is a different design route: it adds mass while retaining combustible insulation. The data do not establish equal roof-PV fire performance. Complete assembly weights must also include deck, vapour control, membrane, fixings, protective layers and PV equipment.

Comparison record for the complete proposed roof

Route: membrane / thermal layer / deck	Thermal basis	Mass basis	Roof-PV fire evidence
Membrane / 200 mm mineral wool / specified steel deck	U = 0.18 W/m²K in cited system leaflet [18]	24 kg/m² insulation only; complete roof mass not established here	Leaflet fire resistance is not a PV fire result. Verify the complete intended roof-PV assembly.
Membrane / cementitious separation layer over PIR / specified deck	PIR thickness and complete U-value require project calculation	Sheet example: 3 kg/m² [17]; complete roof mass not established here	Product-specific test/approval routes in Chapter 13. No automatic equivalence to the other rows.
Membrane / mineral-wool coverboard over PIR / specified deck	Recalculate the full build-up at the same target U-value	Product-dependent added mass; complete roof mass not established here	Material category alone establishes no roof-PV outcome. Obtain assembly-specific evidence.
Membrane / gypsum coverboard over PIR / specified deck	Recalculate the full build-up at the same target U-value	Product-dependent added mass; complete roof mass not established here	Material category alone establishes no roof-PV outcome. Obtain assembly-specific evidence.

A fair project comparison should therefore list, for each complete build-up, its thermal target, total permanent load and the fire outcome demonstrated for that exact configuration. Lightweight mineral-wool coverboards, gypsum boards, cementitious layers and coating/re-cover systems are relevant alternatives where supported by assembly evidence. Their added mass alone cannot rank their protective function. The companion paper Beyond flame spread discusses these categories and their evidence limitations. This paper makes no generic 17 kg/m² saving claim or claim of equivalent fire performance.

FM Property Loss Prevention Data Sheet 1-15 applies the same assembly logic. Its fire objective is to limit fire spread and prevent roof-PV fires from entering the building. For new roofs it directs designers towards FM Approved roof-PV assemblies (FM 4478). For existing roofs receiving PV it recognises retrofit strategies that must be evaluated as complete systems. [4]

> **DESIGN FRAMING (AUTHOR'S PROPOSAL)**
>
> **Do not begin by asking which product should be added. Begin by defining the asset-protection function: the roof-PV system should not provide an easy downward fire pathway from the PV incident into combustible construction and the building below.**

3. Analytical question and design hierarchy

The five frameworks in this paper are intentionally different. NFPA 550 is a fire-safety concepts structure. Bow-tie is barrier-oriented. Event Tree is forward and sequential. Fault Tree is backward and deductive. Defense in Depth is an architecture philosophy. Their value is precisely that they do not share the same analytical lens.

The common test question is therefore narrow and product-neutral: if PV is installed above combustible roof construction, what must the roof-PV design achieve to limit escalation if ignition still occurs?

Design consequence limitation into the roof-PV system as a baseline requirement while continuing to reduce ignition probability.

This baseline is a design requirement, not a reversal of incident chronology and not a claim that prevention is secondary. Electrical design, component quality, installation, inspection, maintenance, monitoring and shutdown remain necessary. The proposition is simply that the building should not depend entirely on every preventive layer succeeding for its survival.

The following five sections apply that same question to each framework.

4. NFPA 550 | Manage the impact

NFPA 550, Guide to the Fire Safety Concepts Tree, provides a structured way to organise fire-safety concepts. At the highest level the tree separates the objective into two broad strategies: prevent fire ignition and manage fire impact. [5]

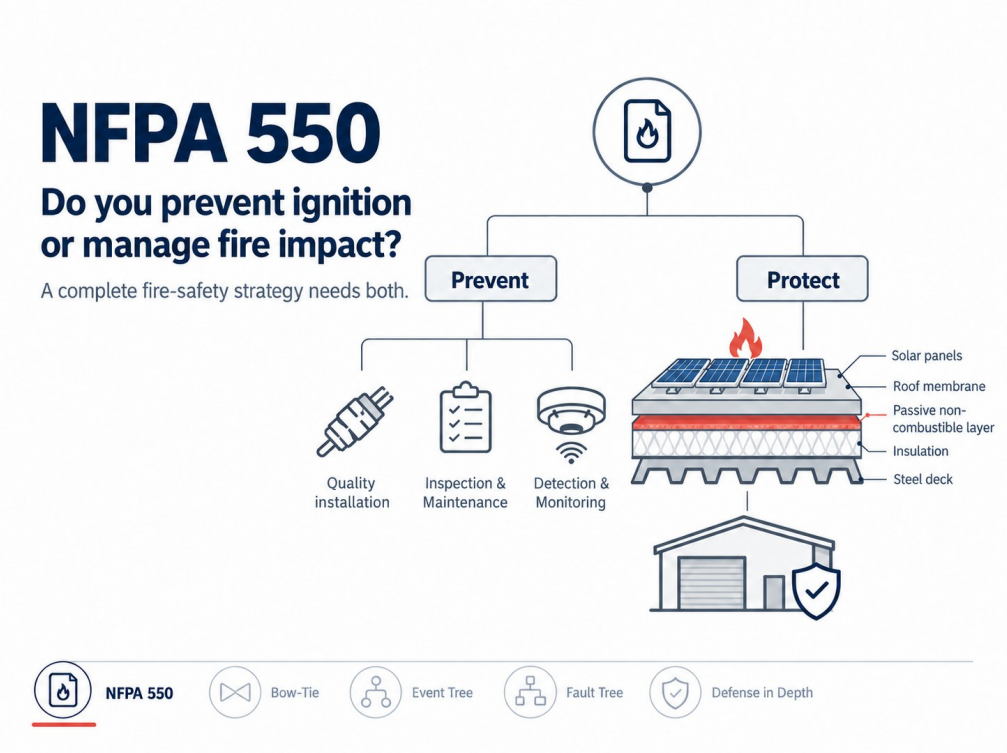


Figure 2. Simplified application of the NFPA 550 logic to a PV roof.

Applied to rooftop PV, connector quality, electrical design, installation, inspection, monitoring and shutdown predominantly sit on the ignition-prevention side. A passive roof measure that continues to perform after a physical fire has already started belongs on the impact-management side.

The important point is not that NFPA 550 specifically prescribes a coverboard. It does not. The inference is that an asset-protection strategy which contains only ignition-prevention measures leaves the impact-management branch underdeveloped.

> **DESIGN IMPLICATION (AUTHOR'S CONCLUSION)**
>
> **If ignition cannot be reduced to zero, fire-impact management must be designed into the roof-PV strategy. For combustible roof construction, that means securing physical separation between the fire exposure and the combustible layers below.**

5. Bow-tie | Protect the consequence side

Bow-tie analysis places a Top Event in the centre, threats and preventive barriers to the left and consequences and mitigating barriers to the right. The Energy Institute and CCPS use the method to make barrier placement and escalation pathways visible. [6]

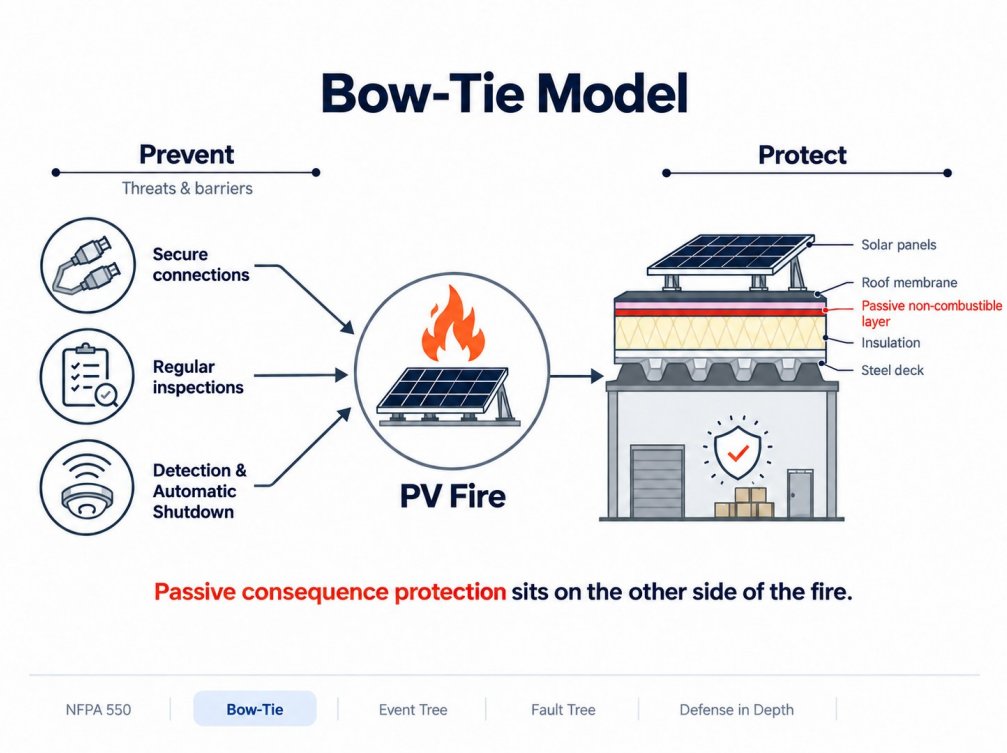


Figure 3. A PV fire as the Top Event: preventive barriers on the left and consequence-limiting protection on the right.

For PV fire risk, most familiar controls sit before the Top Event: component quality, workmanship, inspections, monitoring, arc detection and shutdown. Once a physical PV fire exists, these measures have either already performed or failed to prevent the Top Event. The engineering objective then changes from preventing ignition to limiting escalation.

CCPS distinguishes between barriers that prevent a threat from developing into the Top Event and barriers that mitigate consequences after the Top Event has occurred. [7] A non-combustible physical layer below the membrane is therefore not a competitor to good electrical engineering. It occupies a different position in the risk pathway.

> **DESIGN IMPLICATION (AUTHOR'S CONCLUSION)**
> **If all controls sit before the Top Event, the consequence pathway remains open. A robust roof-PV strategy needs a mitigating barrier between the fire and the asset as well as preventive barriers before the fire.**

6. Event Tree | Interrupt the escalation

Event Tree Analysis starts with an initiating event and follows possible sequences forward. IEC 62502 describes ETA as a method for modelling the consequences of an initiating event as later functions succeed or fail. [8]

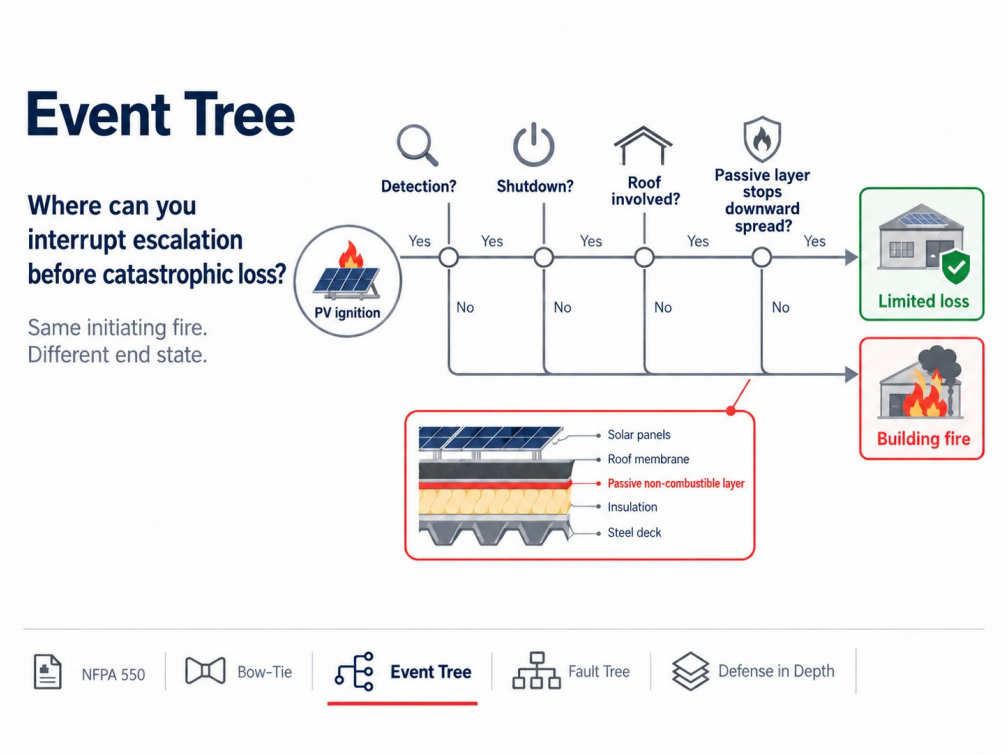


Figure 4. Event-tree logic applied to the escalation from PV ignition to building fire.

A PV fire does not destroy a building in one step. An ignition may be detected, electrical energy may be isolated, the physical fire may or may not involve the roof and the roof assembly may or may not permit further downward propagation. Each branch changes the final state.

This is why shutdown should not be confused with extinguishment. Electrical isolation can work correctly while material that has already ignited continues to burn and expose the roof to heat and flame.

Event Tree thinking also changes how a late barrier is valued. Its importance is not reduced because earlier failures have already occurred. If that barrier separates a local roof incident from internal building fire, it has high consequence leverage.

> **DESIGN IMPLICATION (AUTHOR'S CONCLUSION)**
> **The decisive design task is to create a safe termination point before the sequence reaches internal building fire. A passive non-combustible layer can provide that stopping point in the downward propagation path.**

7. Fault Tree | Break the causal pathway

Fault Tree Analysis works in the opposite direction. IEC 61025 defines FTA as a deductive method for identifying and analysing the events and conditions that can cause a defined undesired state. [9]

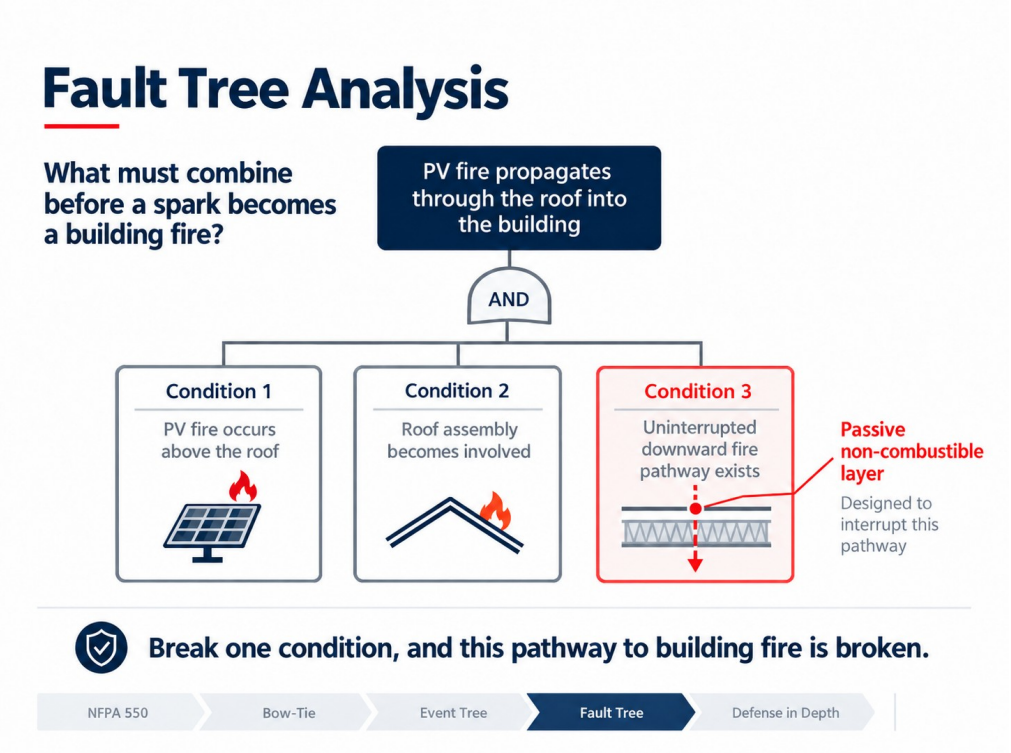


Figure 5. Simplified Fault Tree: one specific path to fire propagation into the building.

Define the Top Event precisely: a PV fire propagates through the roof into the building. A simplified causal pathway requires three conditions to remain available: a PV fire occurs above the roof, the fire exposure involves the roof assembly and an uninterrupted downward propagation pathway remains into combustible construction.

Fault Tree logic is useful because it shows that preventing the initiating fire is not the only way to prevent that specific Top Event. If one necessary condition in an AND-dependent pathway is interrupted, that route to the Top Event is broken.

A complete Fault Tree must also account for other branches such as penetrations, rooflights, edges, expansion joints and equipment details. A passive layer does not make every possible fire pathway impossible. It addresses a defined causal pathway.

> **DESIGN IMPLICATION (AUTHOR'S CONCLUSION)**
> **Engineer the uninterrupted downward fire path out of the roof assembly. A non-combustible separation layer is one way to make that necessary condition unavailable in the intended roof zone.**

8. Defense in Depth | Establish the baseline

Defense in Depth is not primarily an incident-analysis diagram. It is a protection architecture. Nuclear safety guidance from the NRC and IAEA uses multiple levels of protection so that safety does not depend entirely on a single safeguard. Diversity is important because layers with different functions and dependencies are less vulnerable to the same failure mechanisms. [10][11]

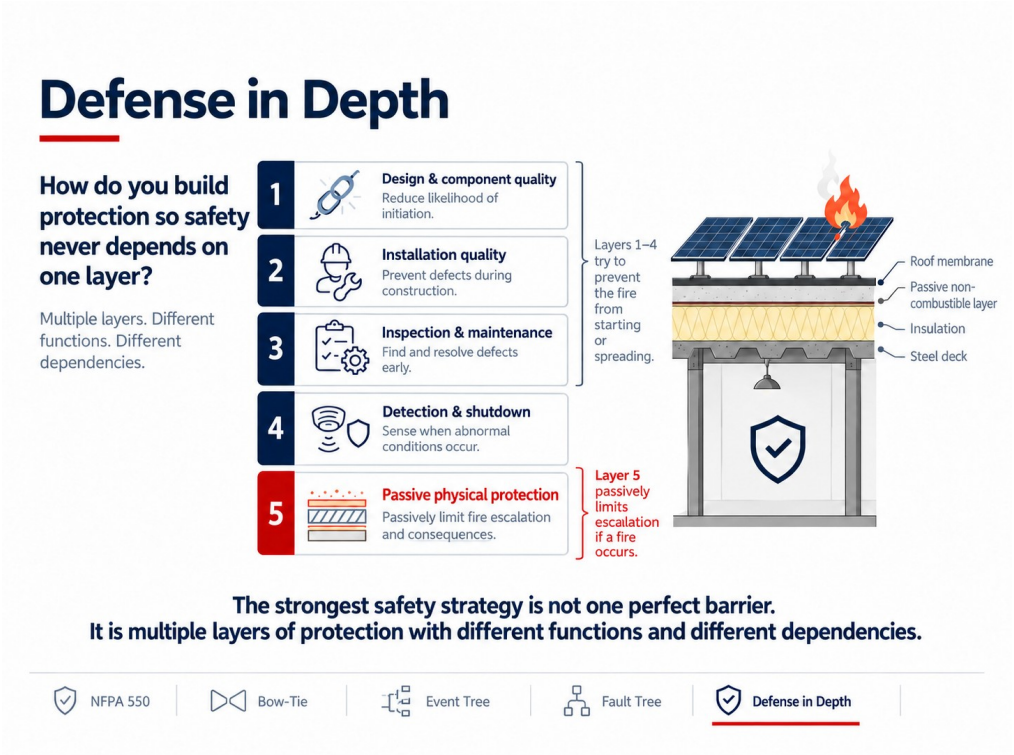


Figure 6. A five-layer PV roof protection architecture derived from Defense in Depth principles.

Applied to a commercial PV roof, the architecture can be expressed as five functional layers: design and component quality, installation quality, inspection and maintenance, detection and shutdown and passive physical protection. This is my application of the Defense in Depth principle, not a formal five-level classification from NRC or IAEA.

The first four layers are themselves different safeguards and should not be treated as though they all fail identically. They can nevertheless share operational dependencies on competent human action, timely detection or active electrical and digital systems.

Passive physical protection has its own design and installation dependencies but its function at the moment of fire exposure does not require power, software, communication or a response to be initiated.

> **DESIGN IMPLICATION (AUTHOR'S CONCLUSION)**
>
> **Treat passive consequence protection as one baseline layer within a protection architecture that also includes probability-reducing controls. The objective is not one perfect barrier but several layers with different functions and different dependencies.**

9. Five frameworks, one design conclusion

The frameworks differ significantly in purpose, method and terminology. None of them can be used as a substitute for another and none of them individually proves the performance of a particular product. Their application in this paper to the same defined scenario supports a consistent design priority. This is an analytical synthesis, not an experimentally validated result or independent evidence that any protective layer is necessary or sufficient.

Framework	What the model exposes	Resulting design priority
NFPA 550	Impact management must exist after ignition.	Secure physical separation.
Bow-tie	A consequence-side barrier is needed after the PV fire.	Place a mitigating barrier between fire and asset.
Event Tree	Escalation needs a safe stopping point.	Interrupt downward propagation before internal fire.
Fault Tree	The Top Event depends on an available propagation path.	Remove or interrupt that necessary condition.
Defense in Depth	Safety should not depend only on preventive and active controls.	Use passive physical protection as a baseline layer.

Design consequence limitation into the roof-PV system as an asset-protection baseline while continuing to reduce ignition probability.

This is an analytical design hierarchy for property protection. It does not mean that preventive measures are optional. It means that the roof-PV design should not depend entirely on ignition never occurring.

10. From individual models to the incident chain

The five frameworks also reveal a practical distinction that matters when controls are selected: a measure can only influence an incident while the relevant escalation step is still available to it.

Connector quality, electrical design, installation and maintenance act primarily before ignition. Once a physical PV fire exists, those measures can no longer determine whether the roof becomes involved. The relevant controls then shift towards the behaviour of the roof-PV assembly itself.

A simplified escalation sequence is: electrical fault → ignition → PV fire → roof involvement → propagation through the roof build-up → involvement of deeper layers → internal building fire.

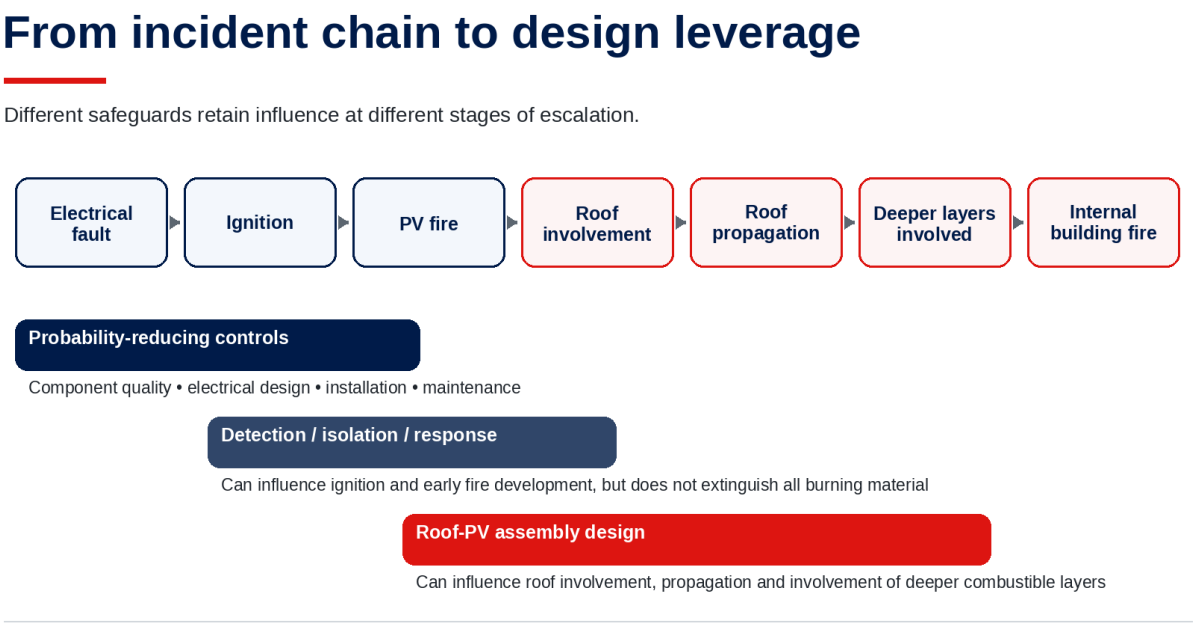


Figure 7. Incident-chain view: safeguards act at different points of influence as an incident escalates.

Viewed as a chain of connected Bow-ties, the consequence state from one stage can become the starting condition for the next. A line of defence therefore has a particular point of influence in that chain.

Different safeguards act at different positions in this sequence. Some have a relatively narrow window of influence. Others can affect several downstream escalation steps by limiting roof involvement, reducing the opportunity for combustible layers to become involved and interrupting propagation towards deeper parts of the roof assembly.

A roof build-up based on non-combustible insulation can reduce the combustible fuel available in the relevant pathway. Other fire-limiting assemblies can retain combustible materials behind a tested protective layer. The engineering question is not whether those strategies are materially identical, but whether the intended roof-PV assembly demonstrates the required consequence-limiting function.

This does not mean that one passive measure controls every fire pathway. Penetrations, rooflights, edges, upstands and other details can create separate escalation routes. The effectiveness of a control therefore has to be assessed against the particular stage and pathway it is intended to influence.

A downstream consequence cannot be managed solely by an upstream control once the incident has already passed that control's point of influence.

11. From risk logic to fire-test evidence

Risk models can define the safety function but they cannot prove that a material or assembly performs that function. That requires evidence. The strongest bridge from theory to specification is therefore to define the required consequence-limiting function and then verify the proposed solution at the complete-system level.

Evidence source	What it contributes	Important boundary	Commissioned / funded by
FM research on rooftop PV fire mitigation	PV changes fire dynamics. Prevention can reduce but not eliminate ignition. Roof-PV assembly fire testing remains necessary.	Research principle, not a product approval.	FM publication / research
ZAG/FRISSBE May 2024 PV fire-safety guideline	Risk must address probability and consequence. Non-combustible insulation is the primary recommendation. Alternatives should demonstrate similar robustness in whole-system multi-module tests.	Guideline principle. It does not prescribe BarrierSheet.	ROCKWOOL and EU FRISSBE (acknowledgements)
ZAG 2025 BarrierSheet fire programme	Across the tested scenarios the barrier prevented direct flame penetration to deeper structural layers while thermal damage and pyrolysis still affected deeper materials.	Specific tested assemblies: one anchored layer over bitumen on EPS, TPO (AS-1) or PVC (AS-2 to AS-4). Localised burn-through in two runs; joints, anchoring and layering influenced results.	AllShield
Kiwa BDA 2024 CLC/TR 50670 programme	In two realistic PV tests an earlier BarrierSheet build-up reduced measured fire spread underneath the barrier relative to spread above it by approximately 40% and 30%. This is a within-assembly comparison, not an improvement relative to a roof without BarrierSheet.	Earlier 1.2 mm BarrierSheet specimen and specific roof/PV configurations.	AllShield Holding B.V. (Kiwa report 24L0241/1, Details: Principal).
FM Approvals PR472014	Current 2.5 mm BarrierSheet is Approved under FM 4470 and FM 4478 in listed assemblies including RoofNav 568563-0-0.	Approval applies to the listed assembly and conditions, not arbitrary substitutions. Previous test data and waivers used; no new PV fire test in PR472014 (§3.2).	AllShield
Efectis 2025 CEN/TS 1187 Test 1	The tested roof assembly recorded no fire penetration, no burning or glowing particles penetrating the roof and no through openings in the four specimens.	Specific double-BarrierSheet assembly. Formal EN 13501-5 classification is assessed separately.	AllShield

The ZAG 2025 programme is particularly useful because it also demonstrates why “no flame penetration” is not the same as “no thermal effect”. The report records subsurface thermal damage, decomposition and local gaps or burn-through areas while still concluding that direct flame penetration into deeper structural layers was prevented in the tested scenarios. [13] That is an important engineering distinction and a reason to treat detailing and full-system behaviour as part of the risk control.

Kiwa’s 2024 tests provide a second useful perspective. They used a realistic PV array above a PVC membrane, BarrierSheet and PIR. The report states that measured fire spread above the fire barrier

compared with damage in the thermal insulation beneath it was reduced by approximately 40% in one test and 30% in the other. That is a comparison within the same assembly; the programme contained no unprotected reference and does not quantify an improvement relative to a roof without BarrierSheet. Temperatures near the barrier reached 575 °C and 837 °C while the highest measured temperature underneath the insulation was 63 °C and 71 °C respectively. [14] These results are specific to the tested arrangements and should not be extrapolated to every roof.

> **EVIDENCE PRINCIPLE**
>
> **The models define what the barrier must do. The fire tests determine whether a specific roof-PV assembly actually does it.**

12. From analysis to a product-neutral design requirement

The combined risk analysis and fire-safety guidance support a product-neutral specification principle rather than a brand statement:

> **PROPOSED RISK-BASED SPECIFICATION PRINCIPLE (AUTHOR'S PROPOSAL)**
> **For PV installed above combustible roof construction, provide an evidenced consequence-limiting roof-PV strategy that prevents or interrupts downward fire propagation into combustible layers and is validated for the intended roof-PV assembly.**

This wording deliberately focuses on function. It also avoids claiming that one material class or one individual product is universally sufficient. The complete assembly, interfaces, attachment, penetrations, roof details and PV configuration remain relevant.

For new construction, a roof build-up based on non-combustible insulation is a route that reduces combustible fuel where practical and is the primary recommendation in the ZAG/FRISSBE May 2024 guideline. [2] For existing lightweight roofs, however, structural reserve can be the governing constraint. Replacing an existing lightweight roof with a much heavier non-combustible insulation build-up may require strengthening of the steel deck or primary structure or may compete directly with the load allowance needed for PV.

As the illustrative comparison in Section 2 shows, roof-system weight differences can be large enough to matter where structural reserve is limited, but no generic kg/m² saving should be inferred from that example. In that situation a lightweight, tested non-combustible separation strategy can be considered, provided that its robustness is demonstrated in representative whole-system fire testing and the complete roof-PV assembly is structurally verified.

This distinction matters. The engineering objective is not to declare the underlying combustible insulation "non-combustible". The objective is to prevent a roof-level PV fire from having an easy propagation route into that combustible material and ultimately into the building.

RC62, the UK insurer-supported Joint Code of Practice for PV installations, is also framed around both prevention and mitigation and calls for additional fire-protection measures where roofing conditions require them. [12] This reinforces the broader industry principle that electrical prevention and building fire protection are complementary risk controls.

The design requirement does not determine one material solution. Depending on the building, roof and applicable evidence, consequence limitation may be achieved through a fully non-combustible roof build-up, an evidenced protective layer over retained combustible materials, an approved retrofit coating or re-cover strategy, or another system-level approach supported by applicable guidance and evidence. These routes are not interchangeable; each has different implications for structural load, wind, waterproofing, constructability, approval and lifecycle. [4]

Five protection objectives

The requirement can be made measurable by separating it into five protection objectives. In bow-tie terms, the first sits before the Top Event and the other four after it. For a risk engineer they can be simplified into three groups: ignition control, fire development and consequence limitation. The objectives are not interchangeable: a measure can perform well against one and have limited effect on another.

Protection objective	Simplified group	Decision question for the risk engineer
1. Prevent ignition	A. Ignition control	Which electrical, installation and inspection measures reduce the probability of a sustained fire, and how reliable are they?
2. Limit fire spread across the membrane	B. Fire development	What extent of membrane-level fire beneath the array is acceptable?
3. Limit direct flame penetration into combustible layers	C. Consequence limitation	What must keep flames out of the combustible insulation, for how long, and in which build-up has that been shown?
4. Limit thermal damage below a protective layer	C. Consequence limitation	What residual heat damage below the layer is acceptable as repair scope?
5. Prevent a roof fire from becoming a building-scale loss	C. Consequence limitation	Which loss scenario is decisive, and which combination of measures keeps it acceptable?

For each objective, the same three questions turn a risk model into an acceptance decision: what residual damage is acceptable, which deviations from tested or approved configurations can be assessed by engineering judgement, and what additional evidence would change the decision. Objective 5 is an outcome rather than a measurable product property; it can only be reasoned from the objectives that tests do measure.

13. BarrierSheet as one evidenced implementation

BarrierSheet is examined here as one evidenced implementation because AllShield has access to the underlying FM Approval and third-party test programmes needed to examine its evidence boundaries in detail. It is not presented as the only route to consequence limitation.

FM Approvals report PR472014 describes the current product as a 2.5 mm formulated cementitious coverboard measuring 1000 x 2000 mm. The report lists two distinct standards. FM 4470 addresses single-ply roof assemblies, including relevant TPO/PVC systems, polymer-modified bitumen sheet, built-up roof (BUR) and liquid-applied roof assemblies for use in Class 1 and non-combustible roof deck construction. FM 4478 is the Examination Standard for Roof-Mounted Rigid Photovoltaic Modules. The evaluated BarrierSheet assemblies meet the applicable requirements of both standards when installed as specified. [15] The programme uses previous test data and waivers, including the FM 4478 external-fire requirement; PR472014 does not document a new fire test with PV (PR472014, §3.2, Table 1).

BarrierSheet's product reaction-to-fire classification is A1 under Efectis report 2026-R000318 [A1]. This classification does not establish the fire resistance of a complete roof.
One listed example is RoofNav assembly 568563-0-0. In that assembly the 2.5 mm BarrierSheet is added to the top insulation layer and used with specified FM Approved PV modules, Sika SolaRoof mounting, Sarnafil TS roof cover, FM Approved insulation and a steel deck. The Approval also includes specific wind, hail and slope conditions. [15]

For an existing roof outside the listed new-build configuration, the listing does not automatically transfer. The route then becomes project-specific FM engineering acceptance, in which FM assesses the actual existing construction and any deviations. Individually approved components do not by themselves form an approved assembly.

The current BarrierSheet Product Data Sheet lists a nominal mass of approximately 3.0 kg/m² ±10% at a nominal thickness of 2.5 mm. [17] That low added dead load is relevant to retrofit feasibility on lightweight industrial roofs, but it does not remove the need for project-specific structural, wind-uplift and complete roof-system engineering.

Its risk function should be described narrowly. BarrierSheet does not prevent a defective connector, does not replace inspection and does not extinguish a PV fire. Its intended role is to create a passive physical separation layer directly beneath the roof membrane so that a fire above the roof has a more difficult path into combustible construction below.

> **BOUNDARIES OF THIS IMPLEMENTATION**
>
> **Most PV controls try to reduce the probability of the Top Event. BarrierSheet is intended to reduce the probability that the Top Event develops into the loss event. Its function at the moment of fire exposure does not depend on detection, power, software, communication or human intervention.**

The third-party fire-test programmes commissioned by AllShield also indicate why the product should be treated as an assembly component rather than as a universal standalone solution. ZAG recorded thermal damage below the barrier despite preventing direct flame penetration in the tested scenarios. [13] Kiwa observed different behaviour depending on test intensity. [14] Efectis (The Netherlands) tested a different double-layer build-up. [16] FM Approval is tied to listed assemblies and conditions. [15]

14. Boundaries, limitations and engineering discipline

A risk-based specification should avoid turning a useful design principle into an absolute claim. A non-combustible coverboard is not a substitute for complete roof detailing, electrical safety or project-specific engineering.

- Roof penetrations, rooflights, drains, expansion joints, parapets, edges and equipment openings can create alternative fire pathways and require specific treatment.
- Wind uplift, hail, structural capacity, drainage, seismic exposure and other natural hazards remain part of the complete roof-PV risk assessment.
- Passive protection depends on correct specification, compatible system selection, workmanship and continuity at details.
- Electrical design, connector quality, installation, inspection, maintenance, monitoring, detection and shutdown remain valuable probability-reducing controls.
- No individual product should be represented as making every possible PV fire scenario impossible.
- Approval, classification or test results apply only within their stated field of application and must not be extrapolated to untested assemblies without engineering justification.

FM's own framework reflects this multi-hazard discipline by addressing fire, wind, hail, electrical design, commissioning, operation and maintenance as parts of the roof-PV risk picture. [4]

> **WHAT THE FIVE MODELS DO NOT PROVE**
>
> **They do not prove that one product is sufficient, that all combustible insulation becomes safe in every configuration or that prevention can be omitted. They define why a consequence-side physical barrier is a rational asset-protection requirement and why its performance must be verified in the complete system.**

15. Conclusion

The question I started from is simple: if PV is installed above combustible roof construction, what must the roof-PV design achieve to limit escalation if ignition still occurs?

Current fire research and guidance now make the context clearer. FM shows that PV changes the roof fire exposure and that good design, installation and maintenance reduce but do not eliminate ignition likelihood. ZAG/FRISSBE's May 2024 guideline states that PV risk must address both probability and consequence and recommends non-combustible insulation as the primary consequence-limiting route, with alternative solutions required to demonstrate similar robustness through whole-system multi-module testing. [1][2]

Five established risk frameworks were then applied to the same design problem. None of them prescribes BarrierSheet or any other specific product. Their value is more fundamental: each exposes a reason why a roof-PV design based only on ignition prevention is incomplete for property protection.

The recurring engineering requirement is to interrupt the physical fire pathway into the building.

NFPA 550 explains why fire-impact management matters. Bow-tie shows why barriers belong on the consequence side of the Top Event. Event Tree shows where escalation can be stopped. Fault Tree identifies a downward propagation pathway as a condition that can be engineered out. Defense in Depth explains why passive physical protection adds value when it has a different function and different runtime dependencies from the preventive layers.

For new roofs, non-combustible insulation and reduced combustible content can reduce the fuel available in the roof build-up; complete assembly performance and detailing still require assessment. For existing combustible roofs, an alternative separation strategy can be justified only by representative system-level evidence. AllShield BarrierSheet is one engineered implementation of that approach and its current FM Approval and the ZAG, Kiwa and Efectis test evidence should be read within the boundaries of the specific assemblies evaluated. [13][14][15][16]

That fire hierarchy sits within a broader roof-first decision sequence. Before rooftop PV is treated as an energy project, the roof should be assessed for structural capacity, roof build-up, service life, fire behaviour, fixing strategy and insurability. What I aim to add with this analysis is a definition of how the fire-consequence question fits into that sequence: before selecting a product, establish the asset-protection function the roof-PV design must perform.

> **FINAL RISK STATEMENT (AUTHOR'S CONCLUSION)**
> **Design consequence limitation into the roof-PV system as a baseline requirement while continuing to reduce the probability of ignition.**

References

[1] D. Zeng, T. Rodrique and D. Boardman, “Evaluation of the Effectiveness of Roof Coating for Mitigating Rooftop Photovoltaic Panel Fire,” 16th International Conference and Exhibition on Fire Science and Engineering (Interflam), Nr Windsor, UK, 2025. Conference programme (paper 258); public overview

[2] Grunde Jomaas, Aleš Jug and Nik Rus. Fire Safety Guideline for Building Applied Photovoltaic Systems on Flat Roofs. ZAG/FRISSBE, May 2024, English version v3. https://www.frissbe.eu/upload/files/FRISSBE-ZAG%20BAPV%20Fire%20Safety%20Guideline%20May%202024%20v3.pdf

[3] QBE European Operations, “Solar panel fires increasing at more than double the rate of installations”, August 2026. Source

[4] FM, Property Loss Prevention Data Sheet 1-15: Roof-Mounted Solar Photovoltaic Panels, April 2026. Source

[5] NFPA 550, Guide to the Fire Safety Concepts Tree, NFPA standard development information. Source

[6] Energy Institute / Center for Chemical Process Safety, Bow Ties in Risk Management: A Concept Book for Process Safety. Source

[7] AIChE / CCPS Process Safety Glossary, barrier terminology. Source

[8] IEC 62502:2010, Analysis techniques for dependability - Event tree analysis (ETA). Source

[9] IEC 61025:2006, Fault tree analysis (FTA). Source

[10] US Nuclear Regulatory Commission, Defense in depth glossary. Source

[11] IAEA, Defence in Depth in Nuclear Safety, INSAG-10. Source

[12] RISCAuthority / Fire Protection Association / MCS / Solar Energy UK, RC62: Recommendations for fire safety with PV panel installations, Version 2, 2023.

[13] ZAG Report 448/25-560-1-EN, About performance comparison of lightweight non-combustible sheet in rooftop PV-related fires, 1 August 2025. Source

[14] Kiwa BDA Testing, Test Report 24L0241/1, external fire exposure to roofs in combination with photovoltaic arrays according to the principles of CLC/TR 50670, 2 September 2024. Source

[15] FM Approvals Report PR472014, AllShield BarrierSheet, FM Approvals Standards 4470 and 4478, Approval date 11 December 2025. RoofNav assembly 568563-0-0. Source

[16] Efectis Nederland, Report 2025-Efectis-R000982, Exposure to external fire to Roofing membrane + BarrierSheet on PIR according to CEN/TS 1187:2012 Test 1, July 2025. Source

[17] AllShield Coatings BV, Product Data Sheet AllShield BarrierSheet AB4478 2026-04, current product dimensions and nominal mass. Source

[18] ArcelorMittal Building Solutions, Globalroof® - Fire solutions for flat folded roofs, EN 11.2025. Published comparison includes 120 mm PIR and 200 mm mineral-wool roof build-ups at U = 0.18 W/m²K and states mineral stone wool density 120 kg/m³. Source

[19] Recticel Insulation, Powerdeck®+ flat-roof PIR insulation, current technical product data: λD = 0.022 W/mK and density approximately 30 kg/m³. Source

Scope note. In this whitepaper I apply risk-engineering methods from a building-engineering and roof-design perspective. It does not replace project-specific code review, insurer requirements, FM engineering review, product approvals, RoofNav conditions or professional fire-engineering judgement. Test results and approvals apply only within their stated fields of application.

About the author

Olivier Langejan is Chief Commercial Officer of AllShield. His architectural and building engineering background informs the series' focus on commercial roof and PV decisions. Authorship, contributions and specialist evidence boundaries are described in Method and sources.

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Method and sources

This is a targeted inventory and synthesis of identified knowledge, updated through the checks documented for 1 November 2026. It does not claim exhaustive coverage of the latest literature. Source findings, author analysis and practical design proposals remain distinct. The author endorses the conclusions within these evidence boundaries.

Authorship and contributions

Olivier Langejan is the lead author, supported by a small team. His professional focus is building and roof design. The papers synthesise the cited research, standards and test evidence; specialist fire-science and electrical findings are attributed to those sources rather than presented as expertise personally established across every discipline. The author endorses the synthesis and its stated limits. AI assistance is described separately below.

Key source boundaries

Approval Report PR472014 (11 December 2025), §§1.3, 3.2 and 9, identifies the applicable standards and evaluated assemblies and refers to RoofNav for the listing. The programme uses previous test data and waivers, including the 4478 external-fire requirement based on 4470 evidence. It does not document a new fire test with PV. Approval of a listed assembly and project-specific engineering acceptance are distinct decisions.
ZAG Report 448/25-560-1-EN, summary p. 3 and conclusion p. 46, reports prevention of direct flame penetration into deeper structural layers in the tested configurations during the documented test periods. Heat transfer, local gaps or burn-through and damage to underlying insulation were also recorded. These observations do not mean that all underlying layers remained undamaged. The programme has no unprotected reference from which a quantified reduction in risk can be calculated.

Scope and selection

This paper synthesises the application of five risk frameworks to escalation from PV above combustible roof construction. Sources were selected for the definitions of the frameworks and for relevant roof-PV fire mechanisms and assembly evidence. The model applications are author proposals. This is not a quantitative frequency model or an exhaustive product comparison.

Sources and dates

The evidence base is the research, standards, approval documents, technical guidance and incident material identified in the references. This is a targeted narrative synthesis, not a systematic review. English-language sources and relevant Dutch or German material are included where cited. The original search dates and a complete search log are not available in the retained publication record, so no reconstructed search period or exhaustive publication cut-off is asserted. Sources retain their individual publication dates. The present editorial and targeted source checks were completed on 1 November 2026.

Publication range

Publication dates and editions are identified for the individual references. This targeted synthesis does not claim exhaustive chronological coverage or a reconstructed complete search period.

Verification

This revision checked the requested wording against the source papers and carried out targeted primary-source checks for the additions and source corrections identified in its revision history. It is not a new claim-by-claim audit of the entire paper. References identify primary documents where available; secondary accounts and access limitations are identified where material. Author interpretations and design proposals do not acquire test or approval status.

Known gaps

No quantified equivalence between mitigation routes or validated building-scale loss-reduction factor is established. The mass examples do not provide a matched fire-performance comparison.

Relationships and commissioning

AllShield commissioned the product-specific ZAG programme 448/25-560-1-EN and other AllShield test programmes cited in this paper. The May 2024 ZAG/FRISSBE guideline is a separate publication; its acknowledgements identify support from ROCKWOOL and the EU-funded FRISSBE project. Sharing an institute or a co-author does not make these different programmes one evidence source. Commissioning and funding are stated where known; unknown funding is not treated as evidence of independence.

Reading evidence

The series distinguishes claim status (DEMONSTRATED, PHYSICALLY SUPPORTED, CONTRADICTED or UNKNOWN) from the route to the intended roof (as tested, formally covered or engineering extrapolated). A cited test demonstrates its observed outcome for the specimen and exposure. Guidance is a recommendation and a proposed framework is author analysis; neither demonstrates a product outcome. A project acceptance decision does not extend the formal scope of evidence.

AI-assisted research and writing

Artificial intelligence was used to help identify and locate technical literature, compare findings across sources, analyse evidence boundaries, organise the argument and assist with drafting and editing. AI-generated summaries were not treated as technical evidence. The selection of sources, interpretation of the evidence, conclusions and final wording remain the responsibility of the author.

Updates

New research, test results, incidents and regulation may lead to new versions. Editorial corrections and technical additions are identified separately in the revision history. Missing sources and evidence that challenges a conclusion are welcome.

About AllShield

AllShield develops passive fire-protection solutions for commercial and industrial roof assemblies, including BarrierSheet. The author is its Chief Commercial Officer.

REVISION HISTORY

Version	Date	Changes
8.5	21 October 2026	Added the five protection objectives with a decision question per objective for the risk engineer. Clarified that the Kiwa 2024 result is a within-assembly comparison without an unprotected reference, added the ZAG build-ups and localised burn-through, and distinguished the FM Approved RoofNav assembly from project-specific FM engineering acceptance on existing roofs. Revision history and series overview introduced with this version.
8.51	1 November 2026	Editorial corrections: reframed as a roof-first knowledge synthesis; shortened the author perspective, added method and source limitations, labelled author interpretations and corrected the requested wording and transparency statements. Technical additions and source checks: Checked the primary roof-system thermal/load leaflet and the English May 2024 ZAG guideline. Replaced the generic weight-saving comparison with a bounded same-function comparison. No unverified matched assembly performance or new product numbers added.
8.52	1 November 2026	Executive summary and Chs. 9, 12–15: bounded the model-derived design hierarchy and material comparisons; corrected ZAG guideline to May 2024. Method and sources: PR472014 §3.2 and ZAG 448/25-560-1-EN pp. 3, 46 evidence limits added. No new test or quantified risk reduction.
8.53	1 November 2026	Ch. 11 evidence table and Ch. 13: FM data/waivers stated beside the claim (PR472014 §3.2); Kiwa commissioning corrected to AllShield Holding B.V. (24L0241/1, Details). References: A1 report 2026-R000318 added. Authorship, methods structure and cover attribution clarified.

THE SERIES

The roof comes first is a synthesis of knowledge on fire safety and rooftop PV from a roof-first perspective, by Olivier Langejan. Each paper stands on its own; together they follow one line of thought.

At the time of this version, the series consisted of:

Paper	For	In one line
Rooftop PV on existing commercial buildings	Asset owners, developers, project teams	A decision framework for resolving roof constraints before the PV investment is committed.
Rooftop PV on new commercial buildings	Developers, architects, project teams	Designing the roof and PV as one system from the start.
The economics of the rooftop PV decision	Asset owners, CFOs, risk managers	Probability, consequence and lifecycle cost from the asset owner's perspective, including Business Interruption.
From risk models to design requirements (this paper)	Risk engineers, insurers, designers	An application of five established risk frameworks to consequence-limiting design for roofs with PV.
Beyond flame spread	Risk engineers, insurers, fire engineers	How far a rooftop PV fire can travel into the roof before it becomes a building loss, and what a separation layer changes.
What does a fire test actually prove?	Insurers, risk engineers, specifiers	What a fire test result does and does not demonstrate about a real roof with PV.
DC arcs as a heat source	Insurers, risk engineers, PV designers	How DC arc faults start, persist and end in rooftop PV.
DC arcs at the roof-PV interface	Insurers, risk engineers, PV and roof designers	What determines roof exposure to a sustained DC arc and what current evidence shows about measures to limit it.
How much does PV clearance actually solve?	Insurers, risk engineers, PV designers, asset owners	What module-to-roof clearance does and does not demonstrate about the roof beneath it.
What if the PV panel could not burn?	Asset owners, risk engineers, insurers, PV designers	What a lower-combustibility PV module does and does not change for the roof beneath it.
What does an inspection actually prove?	Insurers, risk engineers, asset owners, inspectors	What inspection can establish, what it cannot and what still protects the roof when a fault is missed.

All papers and their latest versions: allshield.com/en/olivier-langejan

Comments, corrections, missing sources, evidence that contradicts a conclusion and field experience are welcome at ol@allshield.com. Relevant input is used in future versions. To be notified of new papers and versions, send a short email to the same address.

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