Validation of Roof Configuration 2 Experiments
Project 9

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Introduction

The research described herein expands on previous work conducted over multiple phases of a broader project[1,2,3,4,5,6] to determine the effect of rack mounted photovoltaic (PV) modules on the fire rating of roof assemblies. In general, the experiments demonstrated that the spread of flame ratings of the roof are not maintained when PV modules are installed elevated above the roof. An initial study measured the surface temperature and incident heat flux of a noncombustible room with a noncombustible PV module surrogate installed at 10, 5 and 2.5 inches above the roof. An analysis of the data indicated the 5 inch gap height to be the most critical of the three that were evaluated in terms of increased radiant flux and roof surface temperature. All three gap configurations increased the surface temperature and heat flux on the roof assembly higher than those measured in the absence of the PV module. Subsequent investigations were conducted to develop data for mitigation strategies. These are summarized in Table 1.

Table 1 – Research Summary

Project Number	Discussion
08CA39594, 09CA40917	**Effect of Rack Mounted Photovoltaic Modules on the Fire Classification Rating of Roofing Assemblies September 30, 2009, Revised November 30, 2010** Investigated rack mounted PV modules on roof decks to determine: (1) the effect of PV modules mounted at angles (positive and negative) to steep and low sloped roofs; (2) the impact of PV modules mounted at zero clearance to the roof surface and with the ignition source directed in the plane of the roof or the plane of the PV surface: and (3) the heat release rate and transfer to roof surface of Class A, B, C brands and common materials such as leaf debris and excelsior (wood wool). **Key Findings:** Based on the findings in this report, the installation of a rack mounted PV module on a roof has an impact on the fire resistance ratings of the roof system, regardless of the fire rating of the roof or PV module. For instance, the increase in distance (setback) between the leading edge of the roof and the PV module lessens the chances that the flame will be captured in the gap between the PV panel and roof surface that might otherwise lead to significant burning during the spread of flame test. • A surrogate rack mounted PV module parallel to the roof surface, the fire exposure from the Spread of Flame test resulted in greater temperatures on the roof surface in the area underneath the PV module. In addition, the heat

[1] Effect of Rack Mounted Photovoltaic Modules on the Flammability of Roofing Assemblies, Dated September 30, 2009, Revised March 5, 2010,

[2] Effect of Rack Mounted Photovoltaic Modules on the Fire Classification Rating of Roofing Assemblies, Dated January 30, 2012

[3] Characterization of Photovoltaic Materials – Critical Flux for Ignition / Propagation Phase 3 Dated January 16, 2012,

[4] Determination of Effectiveness of Minimum Gap and Flashing for Rack Mounted Photovoltaic Modules. Phase 4 Dated March 29, 2012

[5] Considerations of Module Position on Roof Deck During Spread of Flame Tests, Phase 5, Dated July 24, 2012

[6] Validation of 42" PV Module Setback on Low Slope Roof Experiments

Project Number	Discussion
	flux on the roof surface also increased. The magnitude of these effects was dependent on the gap size between the module and the roof, as well as the setback distance of the module from the roof leading edge. • For the parameters in this study, it was found that when the gap between the rack mounted PV module and the roof was reduced from 10 inches to 5 inches the measured surface temperatures increased5. It was observed that both the 10 inch and 5 inch gap captured all of the flames, however the smaller gap also reduced the amount of entrained air into the fire plume thus elevating the temperature of exposed surfaces. When the gap size was reduced further to the value of 2.5 inch, the measured surface temperatures did not increase but rather lowered, as the gap was sufficiently decreased to capture only a portion of the flames. • The influence of the setback of the PV module on the measured temperature and heat flux on the roof surface was highest when the PV module was in line with the leading edge (i.e., no setback distance). The measured temperatures and heat flux exposure lessened as the setback distance was extended.
08CA39594, 09CA40917	**Effect of Rack Mounted Photovoltaic Modules on the Flammability of Roofing Assemblies – Demonstration of Mitigation Concepts, Dated September 30, 2009, Revised: February 10, 2010** Investigated the efficacy of some simple mitigation concepts to minimize flame propagation under a roof mounted PV module. These included (i) use of flashing at the leading edge of the roof with control of separation between roof and flashing, and (ii) use of noncombustible back sheet. **Key Findings:** Results showed the limited success of three different mitigation strategies using setback, angled flashing and a screen. • Using only setback as a mitigation strategy, a 36 in setback did not demonstrate compliance to the requirements of Class A for the single test run. • An angled flashing only demonstrated compliance when combined with a 36 in. setback to the requirements of Class A for the single test run. • The 24 and 36 in setback experiments with small sized opening screens were investigated and neither demonstrated compliance to the requirements of Class A. • A vertical flashing (continuous from roofing surface to PV top surface) demonstrated compliance to the requirements of Class A with setbacks of 0, 3 and 12 inches.
10CA49953	**Effect of Rack Mounted Photovoltaic Modules on the Fire Classification Rating of Roofing Assemblies, Dated January 30, 2012** Investigated **Key Findings:** Based on the findings in this report, the installation of a rack mounted PV module on a roof has an impact on the fire resistance ratings of the roof system, regardless of the fire rating of the roof or PV module. For instance, the increase in distance (setback) between the leading edge of the roof and the PV module lessens the chances that the flame will be captured in the gap between the PV panel and roof surface that might otherwise lead to significant burning during the spread of flame test.
11CA43479	**Characterization of Photovoltaic Materials – Critical Flux for Ignition / Propagation. Dated January 16, 2012** Investigated the critical flux for ignition of roofing and PV products. While the

Project Number	Discussion
	individual values varied, most were within the range of the flux values measured on the roof in the original experiments without the PV module in place. **Key Findings:** The critical flux values for most of the roofing products was determined to be greater than the 15 kW/m2 exposure measured on the surface of a noncombustible deck without a PV. Exceptions being one architectural shingle, one membrane and two insulation boards with critical heat flux values of 14, 14, 13, 14 kW/m^2 respectfully. • The critical flux values for all of the roofing products was determined to be less than the 41 kW/m2 exposure measured on the surface of a noncombustible deck with a PV installed with a gap of 5” • The critical flux for ignition of low slope roof products was found to be generally consistent as were the critical flux for ignition of high slope roof products. It should be noted that the roofing products had been evaluated by UL 1703 and have attained a Class A rating either a product in the case of a shingle or as a component of a system in the case of the low slope materials (sheets, insulation, membrane). As such a degree of fire performance would be expected.
11CA43479	**Determination of Effectiveness of Minimum Gap and Flashing for Rack Mounted Photovoltaic Modules. Dated March 29, 2012** Validate the performance of two potential approaches to mitigate the effect of rack mounted PV modules on the fire ratings of roofs: (i) a minimum separation gap; and (ii) a sheet metal flashing to block the passage of flames between the PV module and the roof assembly. **Key Findings:** A continuous flashing was determined to effectively block the passage of flame along the roof under a PV module. A minimum distance of 12 inches above a steep slope (shingled) roof was determined to sufficiently separate the two surfaces to maintain the roof’s original fire rating. Experiments up to a height of 24 inches above a low slope roof resulted in spread of flame in excess of the performance criteria for a Class A roof.
11CA43479	**Considerations of Module Position on Roof Deck During Spread of Flame Tests, Dated July 24, 2012** Investigate a modification of the current UL 1703 spread of flame test to: (1) expose a PV module to flames originating from the UL790 (ASTM E108) ignition source; (2) allow those flames to generate on a representative roof section; and (3) observe the propagation of the flames underneath the candidate PV module being tested. Previous research within Project 1 had been conducted with the PV module installed in a position where both the roof and the module were subjected to the ignition source with zero set back and with only modest set back distances (24 inches or less). The repositioning of the PV module was conducted to investigate an application of first item (roof) / second item (module) ignition sequence. This concept was investigated to refine the understanding of the effect of a rack mounted PV array on the fire rating of a Class A roof. Experiments were conducted on low and steep slope roofs. **Key Findings:** Low slope: • The low slope roof baseline experiment (no PV) exhibited a flame spread of 60 inches.

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Both a noncombustible representation of a PV module or a Class C PV module mounted parallel to and at an elevation of 5 inches above the roof and at offsets of 48 and 52 inches flame spreads were in excess of Class A performance requirements.
A PV module mounted at a slight inclination (10°) to and at an elevation of 5 inches above the roof and at a 48 inch offset did comply with Class A requirements.
A single experiment conducted with two modules angled to the roof (10° inclination), the first offset 24 inches and the second space 12 inches from the first did not comply with Class A requirements.
The overall results of low slope tests with the PVs present were fairly consistent with tests using a surrogate noncombustible PV .

Steep slope:

The steep slope roof baseline experiments (no PV) exhibited a flame spread of 48 inches.
A noncombustible representation of a PV module mounted parallel to and at an elevation of 5 inches above the roof with an offset of 42 inches complied with Class A requirements.
Two experiments conducted with PV modules mounted parallel to and at an elevation of 5 inches above the roof with an offset of 42 inches complied with Class A requirements.
Two experiments conducted with PV modules mounted parallel to and at an elevation of 5 inches above the roof with an offset of 36 inches complied with Class A requirements.
An additional experiment was conducted with a noncombustible sheet mounted parallel to and at an elevation of 5 inches above the roof with an offset of 24 inches and did not comply with Class A requirements
The overall results of steep slope tests with the PVs present were fairly consistent with tests using a surrogate noncombustible PV .
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<tr><td>11CA43479</td><td>Validation of 42” PV Module Setback on Low Slope Roof Experiments Dated December 12, 2012

This series of experiments was conducted to generate data in support of proposed changes to UL 1703, specifically, 42 inch setback of the PV module on low slope roofs.

Key Findings:
The low slope roof baseline (no PV) experiment exhibited a flame spread of 60 inches. This Class A compliant performance is consistent with previous flame spread experiments.

Two of the PV / roof assembly experiments exhibited a flame spread of 42” (Class A compliant) One experiment conducted on the same assembly exhibited a flame spread of 96” (Class A noncompliant).

This inconsistency can be compared to the critical flux determinations of roofing materials as investigated in the third project and reported in “Characterization of Photovoltaic Materials – Critical Flux for Ignition/Propagation, January 16, 2012.” The Critical heat flux for ignition is the lowest thermal load per unit area capable of initiating a combustion reaction on a given material (either flame or smolder ignition). In these experiments, the thermal conditions of the roof / PV assembly configuration are such that fire

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Project Number	Discussion
	propagation along the roof and up under the module are at a critical stage. • Observations of the ignition source flame and the flame emanating from the roof surface indicated the following influencing factors for the different experimental results: o During all of the experiments, the ignition source did not impinge directly onto either the roof surface or the PV module. The roof surface was ignited by radiant heat from the ignition flame. Upon ignition, flames propagated along the roof surface. o During two of the experiments, flames advanced along the roof up to the front of the module (42”), but did not advance further. The flame front was observed to be leaning in the direction of the forward end of the roof deck, opposite of the 12 mph airflow. This observation indicates that the diffusion flame at the roof / PV module interface was drawing combustion air from under the PV module. o During the experiment that resulted in a flame spread of 96”, the flame front demonstrated similar physiognomies as the previous experiments - advancing along the roof up to the roof / module interface. However, during this experiment, the flame front advancement paused temporarily at 42” until ignition of the module as indicated by flames observed along the leading edge of the PV module frame. The flames grew in intensity and extended under the module igniting the module substrate. Once this occurred, flames propagated along the module substrate and roof surfaces. This combination flame front grew quickly extending beyond the roof deck at which time the experiment was terminated by extinguishing the fire.

As described in this report, this project included a series of experiments conducted to generate data on a complete PV assembly / roof configuration including rack and air deflection hardware.

The results of this investigation could be used to:
1. Validate performance of low slope roof test parameters as contained in a draft of a revised test method for consideration by the UL 1703 Standards Technical Panel (STP), and
2. Provide quantitative data to support the proposed standard revisions, specifically, a PV assembly including a module, rack and air deflection hardware mounted on a standardized roof configuration representing roofs with minimal slope.

In addition to the work described above, two additional projects resulted from discussions with PV and roofing industry stakeholders are under consideration. These projects include:
- Project # 6 – A series of experiments to demonstrate generic installation details of PV and roofing systems. If compliant, these details can be documented and used by industry without the need for further evaluation. As of the date of this report, work under Project 6 had not begun.
- Project # 8 – Development of a burner designed to represent the spread of flame along the roof surface. This burner could potentially replace the standard roof configurations described in the UL 1703 proposal improving the test protocol by eliminating variation of the burning roof deck. As of the date of this report, work under Project 8 had not begun.

Samples

Commercially available PV modules and roofing product samples were acquired either through industry donation or purchased from local retailers.

The PV modules were a Class C fire rated metal framed glass on polymer design.

UL 790/ASTM E 108 Class A rated roof deck assemblies consisted of a 60 mil LSFR EPDM (low slope, fire retardant, ethylene propylene diene monomer), and a 70 mil FR EPDM (fiber reinforced ethylene propylene diene monomer) over 4 inch thick polyisocyanurate insulation board mechanically fastened to a combustible deck.

Experiments

Fire performance of the PV modules on roof deck assemblies was investigated by Spread of Flame tests as being considered for proposal to the UL 1703 STP. In accordance with the proposed protocol, multiple experiments were conducted to represent fire approach paths from 3 directions to the array – south, north and east/west.

For these experiments, the objective was to conduct the experiments with the PV assembly (module, rack and air deflector) subjected to a thermal exposure resulting primarily from the burning roof. This was accomplished by positioning the PV assembly with an offset distance as determined by conducting 3 baseline experiments of the roof only.

Scoping Tests

Scoping tests were performed to identify a suitable candidate roofing system to use for the project investigation using UL 790 Class A flame test procedure without the PV module.

An experiment conducted with a LSFR (fire retardant) EPDM membrane roof system resulted in a flame spread distance of 90 inches, which is in excess of Class A requirement.

An experiment with FR (fiber reinforced) EPDM membrane roof system resulted in flame spread distance of 69 inches and was in compliance with the Class A criteria.

This system was selected for the rest of the experiments.

Baseline Tests

Two additional tests were conducted with FR (fiber reinforced) EPDM membrane roof system to determine the extent of flame propagation in the UL 790 flaming mode test for Class A roof systems and calculate the offset distance to be used with PV module tests. The results of three replicate tests are presented in Table 2.

Table 2 – Baseline Test Results

Test Number	Flame Spread Distance (in.)
1	69
2	60
3	54
Average	**61**

An offset distance of 49 in was calculated by subtracting 12 inches from the average flame spread distance.

This offset distance was used in the subsequent tests by locating the leading edge of the PV assembly a distance of 49 inches from the edge of the roof deck edge.

Fire Performance Tests with PV Modules

Four experiments were conducted with the standard low slope roof as described in the current UL1703 proposal being considered by the UL1703 Standards Technical Panel.

The experiments were conducted with aluminum framed glass on polymer PV modules installed on a metal frame providing a 10° inclination to the roof with the lowest portion of the module elevated above the roof ¾ in. The assembly included metal hardware at the sides and back of the module. The PV assemblies were located at a distance of 49 in. from the edge of the roof deck.

The test set-up is shown in Figure 1.

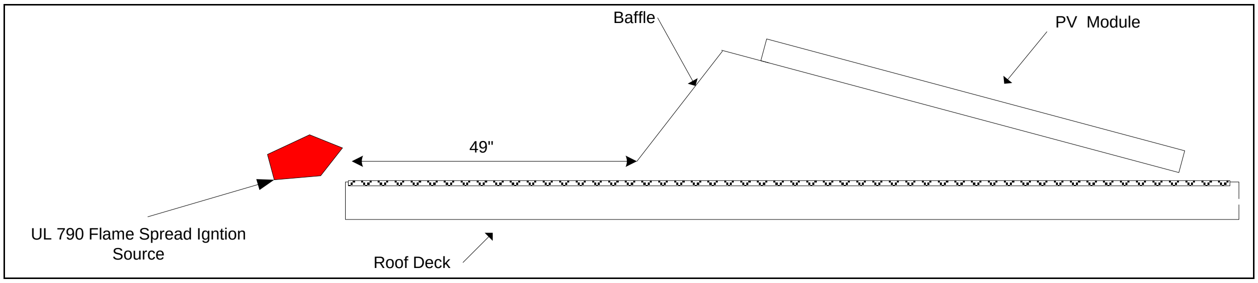

Figure 1 – Test Set-up (North Exposure Shown)

For experiments which included a PV wider than the spread of flame deck, an improvised pedestal mount was temporarily affixed to support the PV assembly. An additional south exposure experiment was conducted to determine the effect of adding an extension to the roof deck (platform) to support a PV assembly which was wider than the width of a standard wood spread of flame roof deck.

1. South Exposure PV / FR EPDM System – “Pedestal” mounting
2. North Exposure PV / FR EPDM System – “Pedestal” mounting
3. East/West PV / FR EPDM System – “Pedestal” mounting
4. South Exposure PV / FR EPDM System – “Platform” mounting

Maximum spread of flame distances and the corresponding time at which they occurred for the various low slope roof assembly experiments are listed in Table 1.

During each of the experiments, the spread of flame extended to less than 6 ft., all were Class A compliant.

Table 1 - Summary of PV / Roof Assembly Experiments

Exp. #	EPDM Membrane	Fire Exp.	PV Offset (in)	Ign. (m:s)	0.5' (m:s)	1.0' (m:s)	2.0' (m:s)	3.0' (m:s)	3.5' (m:s)	4.0' (m:s)	4.5' (m:s)	5.0' (m:s)	5.5' (m:s)	5.75' (m:s)	6.0' (m:s)	6.5' (m:s)	7.0' (m:s)	7.5' (m:s)	Class A Compliant (Y/N)
				Time of Roof Flame Spread															
Experiments conducted January 29, 2013																			
1	LSFR	NA	NA	1:32	1:32	2:16	2:49	3:28		4:04	4:24	5:01	6:07		6:38	7:59	8:46	9:38	No
2	FR	NA	NA	0:54	0:54	1:13	2:15	3:13		3:59	4:59	6:27	8:36	9:46					Yes
3	FR	NA	NA	1:04	1:04	1:37	2:36	3:50		5:04	6:31	9:20							Yes
4	FR	NA	NA	1:06	1:06	1:50	3:04	4:30		7:50	9:31								Yes
Experiments conducted January 28, 2013																			
1	FR	South	49	1:00	1:00	1:48	2:58	4:08	4:52	6:08									Yes
2	FR	North	49	1:06	1:06	1:46	2:55	4:19	6:06	9:02									Yes
3	FR	E/W	49	1:00	1:00	1:41	2:53	4:28	5:25	7:17									Yes
4	FR	South	49	1:00	1:00	1:52	3:05	4:38	5:22	6:50									Yes

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Figure 2 – Figure Illustrating Spread of flame of South Exposure PV / FR EPDM System – "Pedestal" mounting.

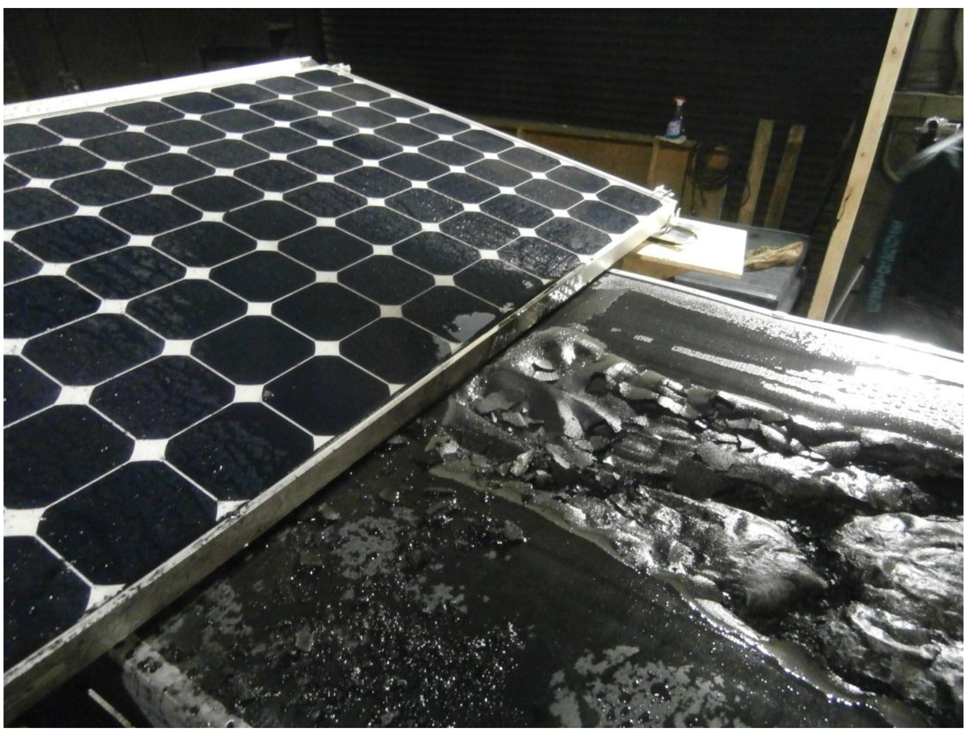

Figure 3 – Figure Illustrating Damage to the PV Module and the Roof Surface.

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Figure 3 – Figure Illustrating Spread of flame of North Exposure PV / FR EPDM System – "Pedestal" mounting.

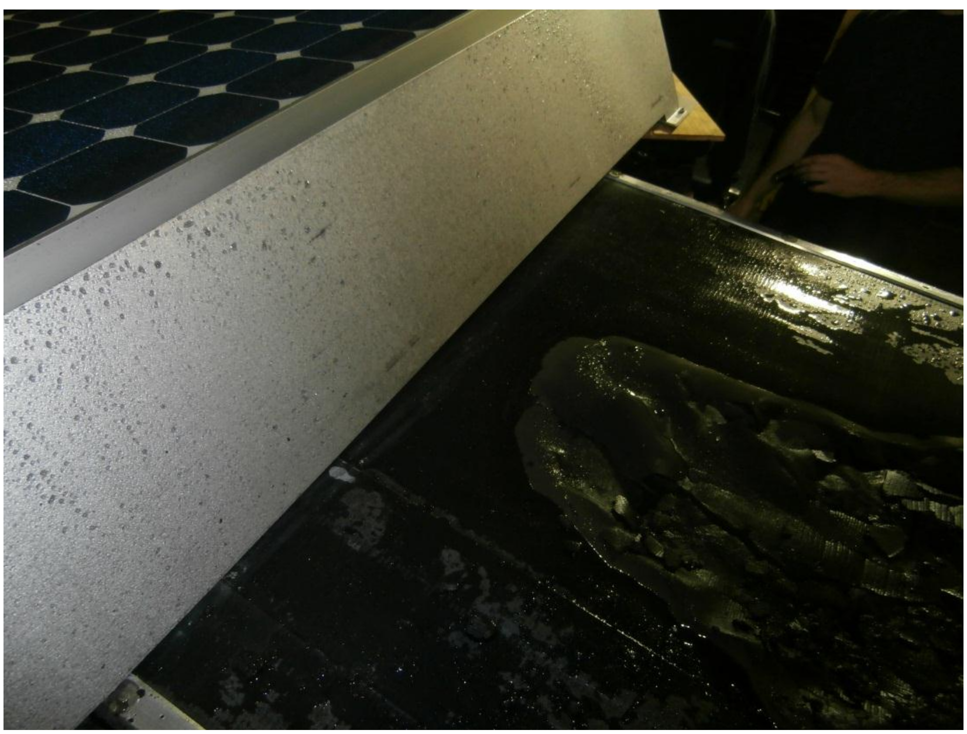

Figure 4 – Figure Illustrating Damage to Roof Surface.

Figure 5 – Figure Illustrating Spread of flame of East/West PV / FR EPDM System – "Pedestal" mounting.


Figure 6 – Figure Illustrating Damage to Roof Surface.

Figure 7 – Figure Illustrating Spread of Flame of South Exposure PV / FR EPDM System – "Platform" mounting.

Figure 8 – Figure Illustrating Damage to Roof Surface.

Summary and Recommendations

Summary of Findings

Although the experiments conducted for this report are not exhaustive, an analysis of the generated data point to the following key findings:

- A minimum slope roof baseline (no PV) experiment conducted with a LSFR EPDM exhibited a spread of flame of greater than 60 inches. This Class A non-conforming performance is inconsistent with previous spread of flame experiments.
- Three minimum slope roof baseline (no PV) experiments conducted with a FR EPDM exhibited a spread of flame of less than 60 inches (Class A).

These experiments indicate a benefit to developing a burner to mimic flame propagation along a roof surface which would minimize variation in PV / Roof assembly testing.

- Four PV / roof assembly experiments incorporating a commercially available rack and baffle system exhibited a spread of flame of less than 60 inches (Class A compliant)
- Observations of the ignition source flame indicated the roof surface ignited and propagated flames up to the PV / rack assembly.
    - During all of the experiments, the ignition source did not impinge directly onto either the roof surface or the PV module. The roof surface was ignited by radiant heat from the ignition flame. Upon ignition, flames propagated along the roof surface.
    - During all of the experiments, flames advanced along the roof up to the front of the inclined module (South exposure) or metal deflector (North and E/W exposures) but did not advance further.
- During the South exposure experiments, thermal damage was observed on the leading edge of the module. In previous experiments, flames and molten droplets were observed in this area along the metal frame. These flames grew in intensity and the fire progressed along the PV substrate and roof surface. In this series of experiments the PV leading edge did not exhibit flaming at the leading edge which can be attributed to the PV module design in addition to the rack and installation details. Another module design with different construction details such as frame, back sheet , encapsulant sealing materials may have exhibited different performance.

Recommendations

These experiments support the recommendations of offsetting the PV assembly at a distance determined by the flame spread of 3 roof only baseline tests as previously reported in:

- Considerations of Module Position on Roof Deck During Spread of Flame Tests, Phase 5, Dated July 24, 2012,
- Validation of 42" PV Module Setback on Low Slope Roof Experiments Dated December 12, 2012

The results of the baseline experiments described in this report illustrate the value of minimizing test variation by replacing the generic roof construction with a burner to replicate flame propagation along the roof surface.