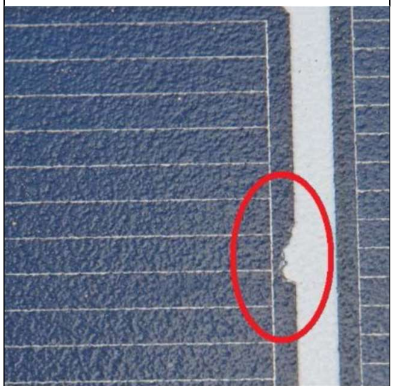
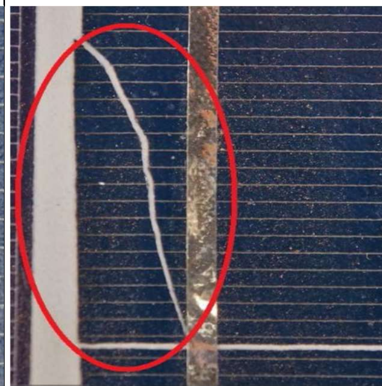
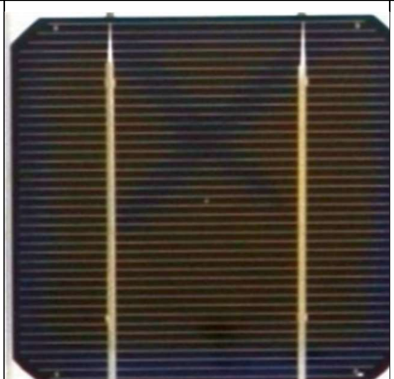
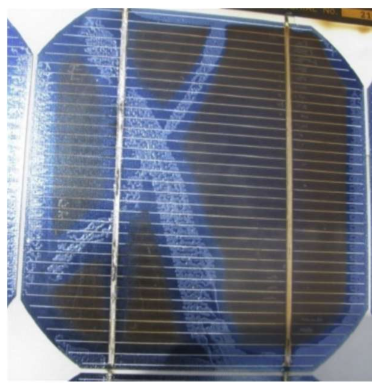
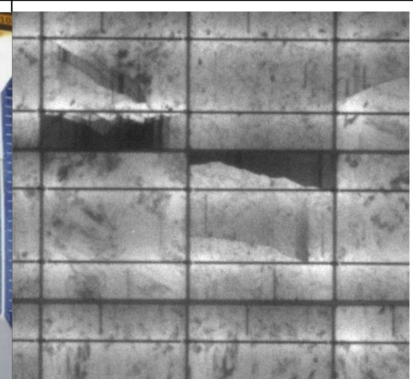
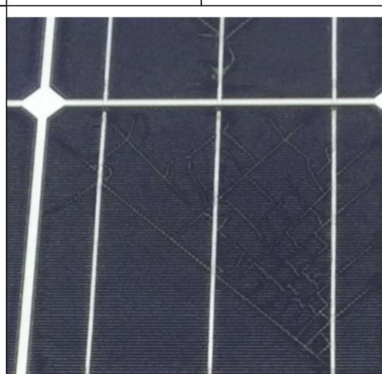
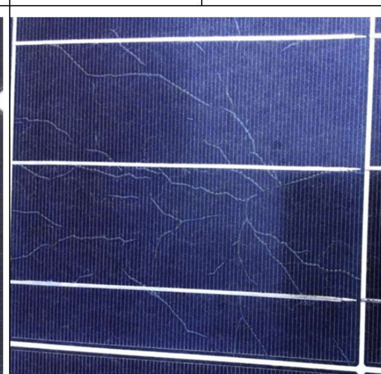
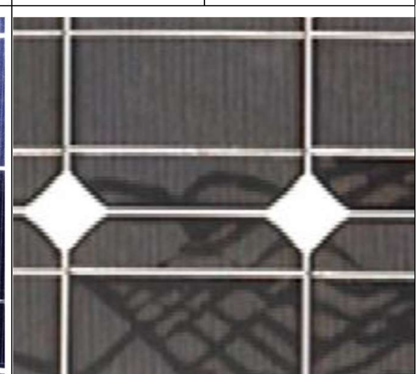
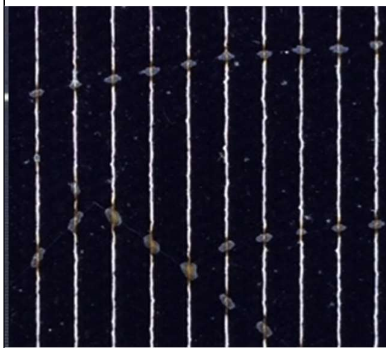
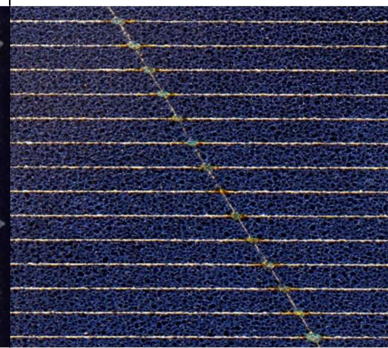
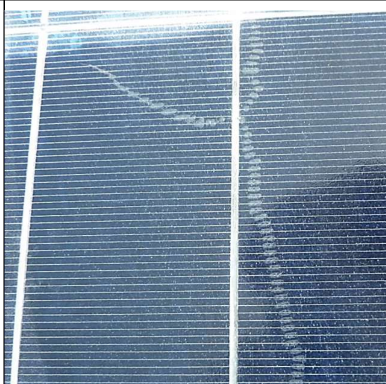
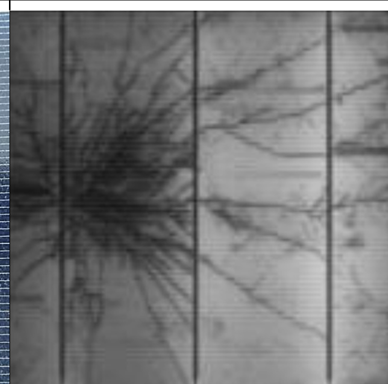
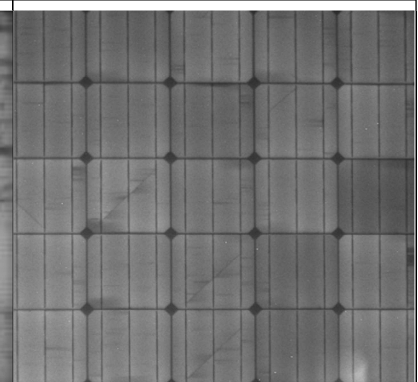
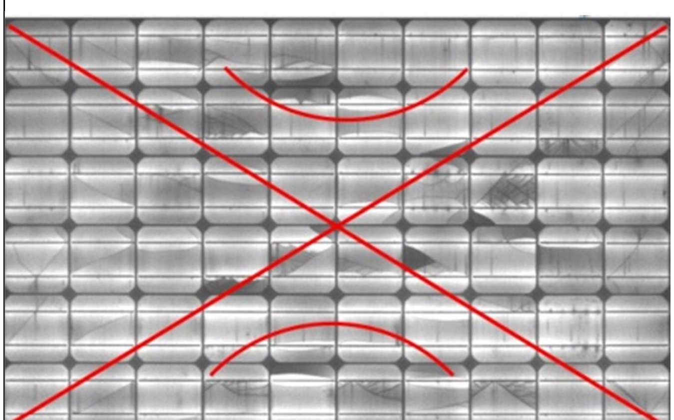
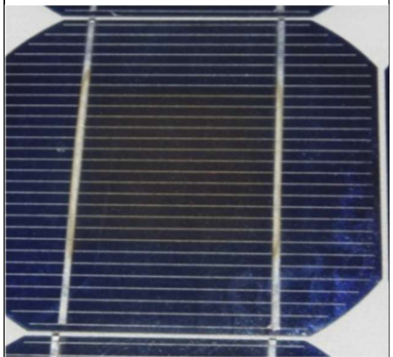
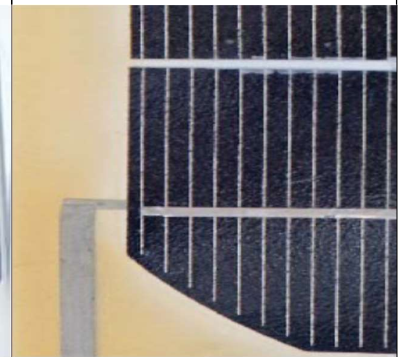
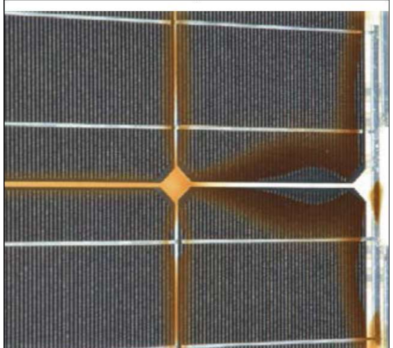
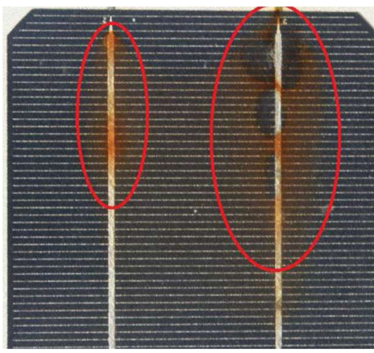
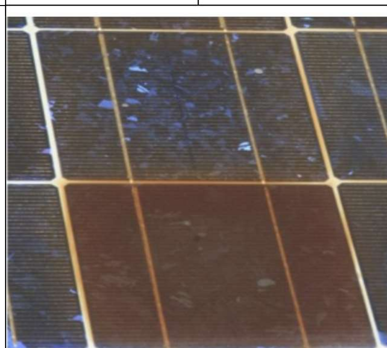
<table>
<tr><td>Component
Defect</td><td colspan="4">Module
Cell cracks</td><td>PVFS 1-1vs.01</td></tr>
<tr><td>Appearance</td><td colspan="5">Cell cracks are cracks in the silicon substrate of the photovoltaic cells. Most of the cell cracks cannot be seen by the naked eye. Only large cracks or where the backsheet is visible through the cracks can be seen. Cell cracks can be easily detected through imaging techniques like electroluminescence, UV fluorescence or lock-in thermography. Cell cracks can have different lengths and orientations (crack patterns). Small cell cracks (micro-cracks) become visible by eye when they form snail tracks or when photobleaching or delamination takes place along the cracks. A snail track is a discoloration of the silver paste of the front metallisation of solar cells which occurs typically 3 months to 1 year after installation of the PV modules. Affected metal fingers on cells may be silver, yellow or brown in appearance, this effect can also be seen on cell edges. Photobleaching is a counteracting effect to the yellowing of the encapsulant and it occurs along the cracks and the borders of the cells. Delamination along cracks is visible as small bubbles.</td></tr>
<tr><td>Detection</td><td colspan="5">EL, UV (IRT, VI ,IV)</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="5">Cell cracks can have origin in all lifetime phases of a PV module: production, installation and operation. In production, cell cracks can occur during wafer, cell and module manufacturing. Especially the stringing and soldering process of the solar cells can damage the cells. After production, major sources for cell cracks are the packaging and transport of the modules, and the installation. After installation, external forces like hail, heavy snow weight or strong wind may result in cell cracks. Once cell cracks are present, further mechanical and thermomechanical stresses can lead to the propagation of the cracks into longer and wider cracks. Some crack patterns can give indications on the origin of the failure, but the final cause of cell breakage is not always easy to identify. A repetitive crack pattern can be for example caused by a production failure, whereas PV modules showing dendritic crack patterns have been probably exposed to heavy mechanical loads. Snail tracks can be found in a great variety of solar modules, but not in all. The combination of different materials (encapsulant and back sheets) with UV radiation and temperature plays an important role in the creation of snail tracks.</td></tr>
<tr><td colspan="2">Production</td><td colspan="2">Installation</td><td>Operation</td></tr>
<tr><td>Impact</td><td colspan="5">Cell cracking does not necessarily lead to a failure of the module. The presence of a crack of any size that does not, or likely will not through its propagation, remove more than 10% of that cell's area from the electrical circuit can be considered to have limited to no impact on the performance. Even if each cell in a 60 cell module is cracked, but do not lead to a separated cell area, the power loss of the module is typically below 2.5 % of the nominal power. In cold and snow climate zones cell cracks seem to have a more pronounced impact. Here relatively high mean degradation rates of up to 7%/y can be found. Besides the risk of power loss there is a risk of hot spots and burn marks due to inactive cell parts. Snail tracks are reported to have no influence on the performance of the PV module, but due to the observed porous silver fingers the isolation of cracked cell parts may be accelerated more than it would be without snail tracks.</td></tr>
<tr><td></td><td>Safety:</td><td>
</td><td>Performance:</td><td colspan="2">
</td></tr>
<tr><td rowspan="2">Mitigation</td><td colspan="2">Corrective actions</td><td colspan="2">Preventive actions (recommended)</td><td>Preventive actions (optional)</td></tr>
<tr><td colspan="2">Modules with a direct safety risk or a severity of 5 should be replaced. Regular inspections should be done to monitor the status of the not replaced modules.</td><td colspan="2">Adequate transport procedures, installation and cleaning by trained personal, in case of higher snow or hail risk use of therefore certified modules.</td><td>Request EL pictures from production, pre-shipment or warehouse inspection, EL images with mobile laboratory before or during installation, regular EL inspection or after sever weather conditions.</td></tr>
</table>

EXAMPLES (page1)			**PVFS 1-1vs.01**
Examples 1-3			
	Cell chipping. A very small region is missing from the edge of the cell, but does not enter metallized region. [Köntges14]	Large crack at cell corner visible by eye - small portion of the cell (<10%) is no longer electrically connected. [Köntges14]	Cell crack with snail track. No isolation of any cell part. The propagation could isolate a cell area >10%. [Köntges14]
Severity	1	2	2
Examples 4-6			
	Cell cracks visible by the photobleaching effect. This may not be mistaken for snail tracks. [Köntges14]	Two cell cracks with extensive delamination, EVA browning and photo bleaching. [Yang19]	EL image of 2 cell cracks which isolates more than 10% of the cell area. [TUV Rheinland]
Severity	f e 2 3 4	f e 2 3 4 5	f e 2 3 4
Examples 7-9			
	Snail track example. [Yang19]	Snail track example. [Yang19]	EL of cell cracks with snail tracks. [Köntges14]
Severity	f e 2 3 4	f e 2 3 4	f e 2 3 4

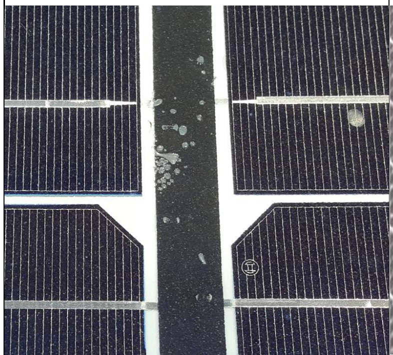
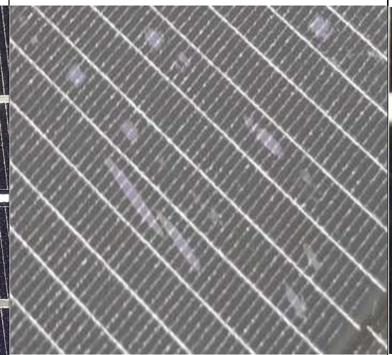
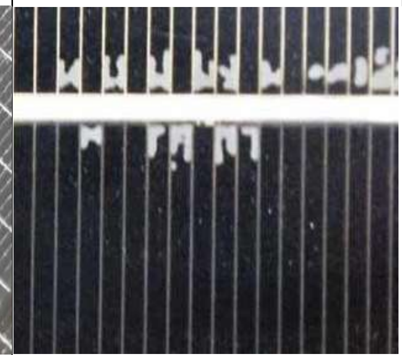
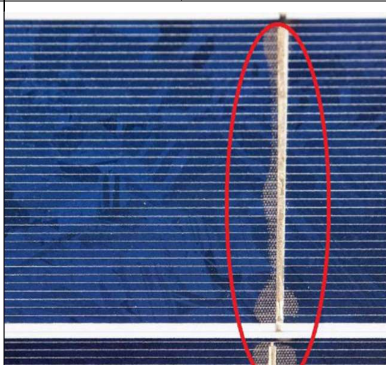
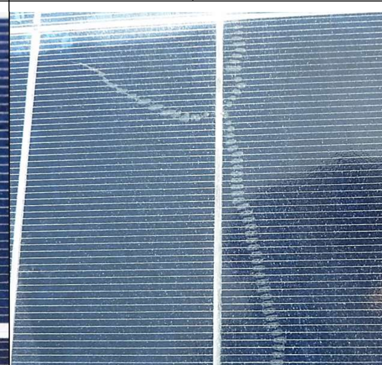
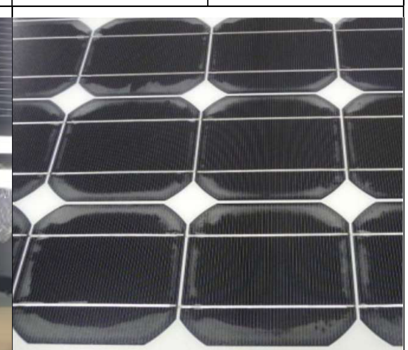
EXAMPLES (page2)			**PVFS 1-1vs.01**
Examples 10-12			
	Zoom of snail track with delamination. [Yang19]	Zoom of snail track with browned fingers. [Sinclair17]	Zoom of snail track with delamination. [SUPSI]
Severity	f e 2 3 4	f e 2 3 4	f e 2 3 4
Examples 13-15			
	Cell crack with EVA delamination. [TUV Rheinland] (see also PVFS 1-3)	Typical EL picture of a cell crack caused by hail. [TUV Rheinland]	Repetitive crack pattern due to impact of soldering machine. [SUPSI]
Severity	f e 2 3 4	f e 2 3 4	2
Examples 16			
	Typical EL picture of cell cracks caused by a heavy homogeneous mechanical load (X-crack pattern) also without glass breakage. [Köntges14]		
Severity	f e 3 4		

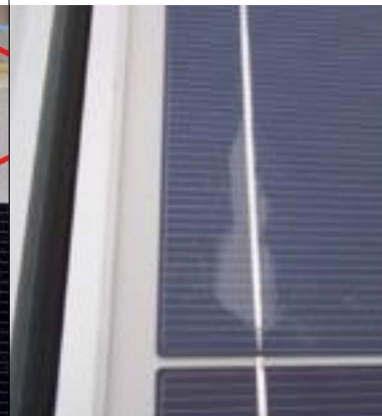
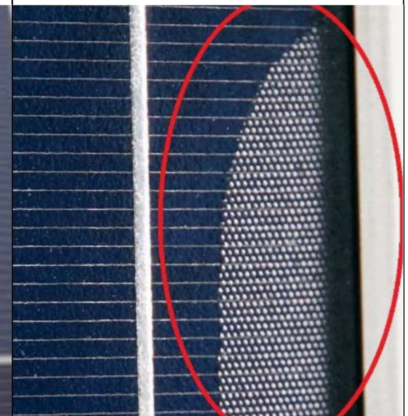
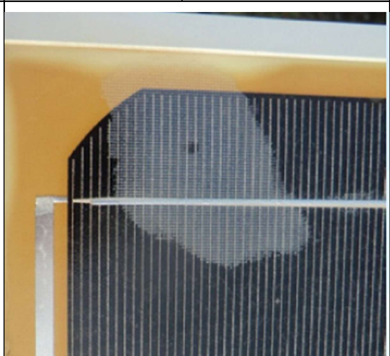
<table>
<tr><td>Component
Defect</td><td colspan="4">Module
Discolouration of encapsulant or backsheet</td><td colspan="2">PVFS 1-2vs.01</td></tr>
<tr><td>Appearance</td><td colspan="6">The degradation of the encapsulation or backsheet materials is getting visible as a light yellow to dark brown discolouration. Colour can be next to or above the cells, along the busbars or cell interconnects or on the back or front side of the backsheet. Often discolouration is inhomogeneous and follows spatial patterns depending on the type of module construction. Typically, for glass/backsheet modules the browning occurs in the central region of the cells with wide clear encapsulant areas, or “frames” around the cell edges. Discolouration can also be observed in the encapsulant between neighbouring solar cells when the front side of the backsheet (layer behind the cells) is degrading. For glass/glass module constructions the encapsulant discolouration is mostly spatially uniform, but can also show patterns of clearer areas over some cells. In glass/backsheet modules the location of these patterns generally correlates with cell cracks. In some cases, the discolouration is more pronounced in one or more cells of the module.</td></tr>
<tr><td>Detection</td><td colspan="6">VI, (IV, IRT)</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="6">In the past, yellowing or browning was mostly associated with the degradation of the mostly used encapsulant ethylene vinyl acetate (EVA) but this problem was greatly solved by improved stabilisation of the polymer with additives, including UV absorbers and thermal stabilizers. If the choice of additives and/or their concentrations are inadequate, or the lamination process is inadequate or incomplete, the encapsulation material may discolour over time. The patterns of discolouration observed in the field can be very complex because of the diffusion of oxygen or the products of reaction, such as acetic acid, generated when heat and UV light interact with EVA. The presence of oxygen leads to the so called photobleaching effect which creates a ring of transparent EVA around the perimeter of a cell or a cell crack. The case of single cells which are far darker than the adjacent cells, implies that the most discoloured cell was at higher temperature than the surrounding cells, perhaps because of differences between the cells or the cell being located above the junction box.</td></tr>
<tr><td colspan="2">Production ■</td><td colspan="2">Installation □</td><td colspan="2">Operation ■</td></tr>
<tr><td rowspan="2">Impact</td><td colspan="6">Discoloration is a sign that the polymeric compounds within the module started to degrade. This type of degradation is predominantly considered to be first an aesthetic issue before a decrease of module current and power production is detected. Typically, mean yearly degradation rates due to yellowing are about 0.5%/a and may reach up to 1%/a in hot and humid or moderate climates. While it is uncommon for EVA discolouration to induce other failures within the cell, it may correlate to: high temperatures in the field, the generation of acetic acid and concomitant corrosion and embrittlement. Unless discolouration is very severe and localized at a single cell, where it could cause a substring bypass-diode to turn on, the discolouration of EVA does not present any direct safety issues. More critical is the discolouration of UV sensitive backsheets that can result in a loss of mechanical properties (elastic behaviour) and cracking of backsheet due to thermomechanical stresses.</td></tr>
<tr><td>Safety:</td><td colspan="2">f e</td><td>Performance:</td><td colspan="2">1 2 3</td></tr>
<tr><td rowspan="2">Mitigation</td><td colspan="2">Corrective actions</td><td colspan="2">Preventive actions
(recommended)</td><td colspan="2">Preventive actions
(optional)</td></tr>
<tr><td colspan="2">Modules with a direct safety risk or a severity of 5 should be replaced. Regular inspections should be done to monitor the status of the not replaced modules.</td><td colspan="2">Check validity of IEC 61215 certification and BOM.</td><td colspan="2">Regular system inspections

For areas with harsh climate, request modules pass higher test standards, like double or triple IEC 61215 test condition.</td></tr>
</table>

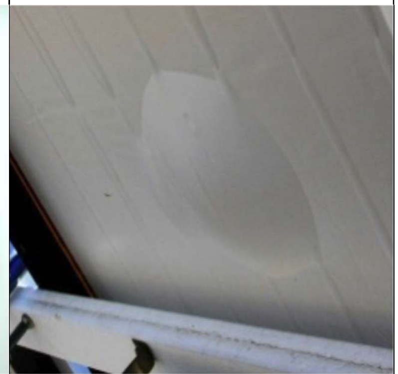
EXAMPLES (page1)						**PVFS 1-2vs.01**
Examples 1-3						
	Slightly browned EVA in the centre of the cell with photobleaching at the edges. [Köntges14]		Slightly browned EVA in the centre of the cell with photobleaching at the edges. [India18]		Yellowed backsheet from the inside. [Sinclair17]	
Severity		2		2 3		1 2
Examples 4-6						
	Dark discolouration at cell edges, between cells and over gridlines and busbars. [Sinclair17]		Dark discolouration over metalization. [Sinclair17]		Backsheet air side yellowing. [Sinclair17]	
Severity		2 3		2 3	e	1 2
Examples 7						
	Single cell browned much faster than the others due to local heating. [Köntges14]					
Severity	f e	2 3				

<table>
<tr><td>Component
Defect</td><td colspan="4">Module
Front delamination</td><td>PVFS 1-3vs.01</td></tr>
<tr><td>Appearance</td><td colspan="5">Any local separation of the layers between (i) the front glass and the encapsulant or (ii) the cell and the encapsulant, visible as bubbles or as bright, milky area/s. It may appear continuous or in spots. The position and size of the delamination or bubble depends on the origin and progress of the failure.</td></tr>
<tr><td>Detection</td><td colspan="5">VI, (INS)</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="5">The adhesion between the glass, encapsulant, active layers, and back layers can be compromised for many reasons. Typically, it is caused by the manufacturing process (e.g. poor cross linking of EVA, too short lamination times, too high pressure in the laminator, contaminations, improper cleaning of the glass, incompatibility of EVA with soldering flux, inadequate storage of the raw material) or environmental factors (e.g. thermal stresses, external mechanical stresses, UV). Delamination is generally followed by moisture ingress and corrosion. It is therefore more frequent and severe under hot and humid conditions.</td></tr>
<tr><td colspan="2">Production ■</td><td colspan="2">Installation □</td><td>Operation ■</td></tr>
<tr><td rowspan="2">Impact</td><td colspan="5">Delamination or bubbles do not automatically pose a safety issue, but they can result in reduced insulation of the component and increased safety risk when they form a continuous path between electric circuit and the edge due to possible water ingress. Moisture in the module will decrease performance due to an increase of series resistance, affect long term reliability and in some cases also the structural integrity of the module. Moreover, delamination at interfaces in the optical path will result in additional optical reflection and subsequent decrease in current. This can be the origin of current mismatch. If the mismatch is significant, it will trigger the bypass diode and cause further power loss. The inverter might also shut down due to leakage current's leading to a further performance loss. Manufacturing related delamination issues often affects a relevant percentage of modules within the same production batch and consequentially has a big impact on system performance.</td></tr>
<tr><td>Safety:</td><td>f e e</td><td>Performance:</td><td colspan="2">1 2 3 4 5</td></tr>
<tr><td rowspan="2">Mitigation</td><td colspan="2">Corrective actions</td><td colspan="2">Preventive actions (recommended)</td><td>Preventive actions (optional)</td></tr>
<tr><td colspan="2">Modules with a direct safety risk or a severity of 5 should be replaced. Regular inspections should be done to monitor the status of the not replaced modules. In case of individual module testing all modules which failed the insulation and/or wet-leakage test should be replaced.</td><td colspan="2">Check validity of IEC 61215 certification and BOM, ground fault detection by inverter or other devices at all time.</td><td>Extended testing (e.g. damp heat), pre-shipment inspections (e.g. cross linking level of EVA) regular visual system inspections.</td></tr>
</table>

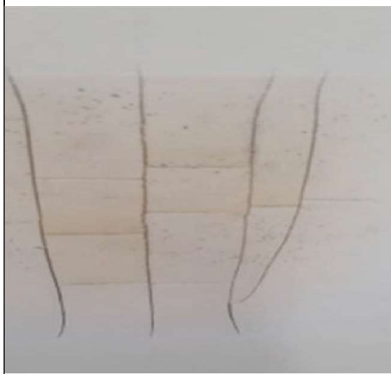
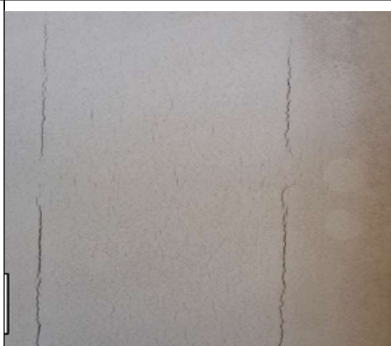
EXAMPLES (page1)			**PVFS 1-3vs.01**
Examples 1-3			
	Encapsulant delamination in un-critical position. [SUPSI]	Encapsulant delamination from cell caused by production pro-cess. [SUPSI]	Encapsulant delamination from cell along grid fingers and bus bar. [Packard12]
Severity	1	1 2	1 2
Examples 4-6			
	Encapsulant delamination from glass (spotted due to glass tex-ture) along the bus bars. [Pack-ard12]	Encapsulant delamination along a cell crack. [Köntges16] (see also PVFS 1-1)	Encapsulant delamination near cell edges in combination with cell browning. [Packard12]
Severity	1 2	f e 2 3 4	2 3
Examples 7-9			
	Delamination in front of cell in the centre of the module. [Moser17] (see also FS 1-2)	Delamination at module insert connections of a glass/glass module (junction box). [SUPSI]	Delamination at cell edges. [Könt-ges14]
Severity	2 3 4	e 1 2	e 2 3 4

EXAMPLES (page2)			PVFS 1-3vs.01
Examples 10-12			
	Encapsulant delamination at borders. [Sinclair17]	Encapsulant delamination along a bus-bar in a cell close to the module edge. [Moser17]	Encapsulant delamination of from glass (spotted due to glass texture) at the edge of the cell. [Sinclair17]
Severity	e 1	e 1 2	e 2 3
Examples 13-15			
	Delamination creating a continuous path between electric circuit and the edge. [Moser17]	Delamination with corrosion. [Köntges17] (see also FS1-11)	Delamination caused by detachment of backsheet with exposure of encapsulant from the back. [SUPSI]
Severity	e 3 4 5	e e 3 4 5	e 3 4 5

Component Defect	**Module** **Backsheet delamination**		**PVFS 1-4vs.01**
Appearance	Any local separation of the polymeric back sheet layers leading to an air gap between the backsheet and the rest of the module, or within the multilayer backsheet (=internal delamination). The backsheet may appear wavy, with locally limited bumps, bubbles or ripples. In the worst case, one or more layers may peel off. The position and extent of the delamination will depend on the cause and progression of the failure.		
Detection	VI, (INS)		
Origin	There are many different forms and compositions of polymeric multilayer backsheets on the market. With laminated backsheets (polymeric layers adhered to each other by a thin adhesive layer) internal delamination can appear: the multiple layers may delaminate upon adhesive degradation, which may lead to local delamination of two subsequent layers or a peel-off of one or more layers. Co-extruded backsheet are prone to internal lamination. Delamination of the backsheet from the encapsulant can appear with all types of backsheets and originates from a lack of adhesion between the backsheet and the encapsulation. The major drivers for the delamination of or within the the backsheet are (i) thermo-mechanical stress originating from differing CTE of the individual polymeric layers, (ii) chemical reactions at the interfaces (material incompatibility) or deteriorated interfacial bonding as a result of the attack from heat, UV and moisture or (iii) external mechanical stress applied on the module. Therefore, it is more frequent and severe under hot and humid conditions. Delamination can be also caused by an insufficient lamination process e.g. too short lamination times.		
	Production ■	Installation □	Operation ■
Impact	If delamination occurs forming bubbles in a central, open area of the back, it will not present an immediate safety issue. That area would likely operate at slightly higher temperatures as the heat conduction/dissipation through the backsheet is disturbed. But as long as the bubble is not further mechanically cracked or expanded, the performance and safety concerns are minimal. However, if delamination of the backsheet occurs near a junction box, or near the edge of a module there would be more serious safety concerns. Delamination at the edge may provide a direct pathway for liquid water to enter the module during a rainstorm, or in response to the presence of dew. That can provide a direct electrical pathway to ground creating a very serious safety concern. Similarly, delamination near a junction box can cause its loosening, putting mechanical stress on live components with the danger of breakage. A break might cause a connection failure to a bypass diode and possibly result in an unmitigated arc at full system voltage. In multilayer backsheets the severity depends also on which layer is affected.		
	Safety: 	Performance: 	
Mitigation	Corrective actions	Preventive actions (recommended)	Preventive actions (optional)
	Modules with a direct safety risk or a severity of 5 should be replaced. Regular inspections should be done to monitor the status of the not replaced modules. In case of individual module testing all modules which failed the insulation and/or wet-leakage test should be replaced.	Check validity of IEC 61215 certification and BOM. Ground fault detection by inverter or other devices at all time.	Regular system inspections.

EXAMPLES (page1)			PVFS 1-4vs.01
Examples 1-3			
	Multiple bubbles in the centre and edge of the backsheet. [Köntges16]	Blisters because of vapour barrier, such as aluminium foil. [Köntges17]	Big central bubble + wavy delamination. [Köntges14]
Severity	e — 2 3 4	e e — 1 2 3 4	e — 1
Examples 4-5			
	Backsheet delamination with direct exposure of encapsulant. [SUPSI]	Delamination of top layer without exposure of encapsulant. [SUPSI]	
Severity	f e — 2 3 4	f e — 1 2 3	

<table>
<tr><td>Component
Defect</td><td colspan="6">Module
Backsheet cracking</td><td>PVFS 1-5vs.01</td></tr>
<tr><td>Appearance</td><td colspan="7">Any damage of the backsheet (surface or whole stack) that is visible as crack, burst or scratch. The location and extent of the cracks depend on the cause and progression of the failure. The cracked area may be localized (e.g bursted bubble, scratch), extend along specific module areas (e.g. long or between the cells, along the busbars) or extend over large or the full area of the module (e.g embrittled surface). The crack can be very deep and affect the back sheet stack.</td></tr>
<tr><td>Detection</td><td colspan="7">VI, (INS)</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="7">The degradation of the backsheet can be caused by environmental factors like UV-irradiation, thermal stress, external mechanical stress or by internal stress (e.g. thermomechanical stress with the multimaterial composite PV-module) or incorrect handling during transport and installation (local cuts, scratches). Deep backsheet cracking (whole backsheet stack split) is often followed by moisture ingress and corrosion. This is more frequent and severe under hot and humid conditions. The use of low quality material (e.g. low UV resistance) or incompatible material combinations (backsheet ↔ encapsulant) causes most of the premature degradation failures. Discolouration and or strong chalking can be precursors for backsheet cracking. Deep cracks or bursted bubbles can be the result of local hotspots/burn marks that split or break the backsheet.</td></tr>
<tr><td colspan="2">Production ■</td><td colspan="2">Installation ■</td><td colspan="3">Operation ■</td></tr>
<tr><td rowspan="2">Impact</td><td colspan="7">A broken backsheet can cause electrical insulation failure, posing a safety hazard and a potential ground fault. On the long-term, power degradation due to the penetration of moisture into the module which induces further failures (e.g. corrosion, delamination) can occur. In the case of deep cracks reaching the active part of the cells, the insulation is immediately compromised and safety is not anymore fulfilled.</td></tr>
<tr><td>Safety:</td><td colspan="2">f e m e</td><td>Performance:</td><td colspan="3">1 2 3 4 5</td></tr>
<tr><td rowspan="2">Mitigation</td><td colspan="2">Corrective actions</td><td colspan="2">Preventive actions (recommended)</td><td colspan="3">Preventive actions (optional)</td></tr>
<tr><td colspan="2">Modules with a direct safety risk or a severity of 5 should be replaced. Regular inspections should be done to monitor the status of the not replaced modules. In case of individual module testing all modules which failed the insulation and/or wet-leakage test should be replaced.</td><td colspan="2">Ground fault detection by inverter or other devices at all time, check validity of IEC 61215 certification and BOM, visual inspection before installation.</td><td colspan="3">Regular system inspections.</td></tr>
</table>

EXAMPLES (page1)			**PVFS 1-5vs.01**
Examples 1-3			
	Cracked backsheet in combination with yellowing under a hot cell. [Eder19]	Squared cracks beneath cell interspaces. [Eder19]	Cracking between cells. [Packard12]
Severity	f m e / 2 3 4 5	f m e / 2 3 4 5	f m e / 2 3 4 5
Examples 4-6			
	Longitudinal cracks located under bus bars. [Eder19]	Backsheet cracking. [DuPont20]	Backsheet cracking. [DuPont20]
Severity	f m e / 2 3 4 5	f m e / 2 3 4 5	f m e / 2 3 4 5
Examples 7-8			
	Localized superficial damage. [Köntges17]	Deep scratch on backsheet. [TUV Rheinland]	
Severity	f e m / 1	f m e / 1 2	