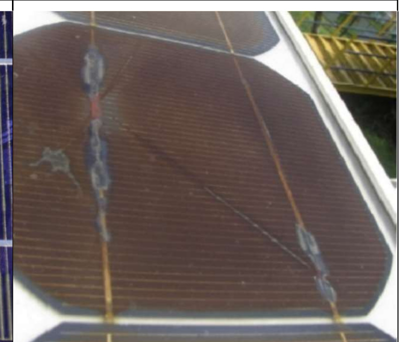
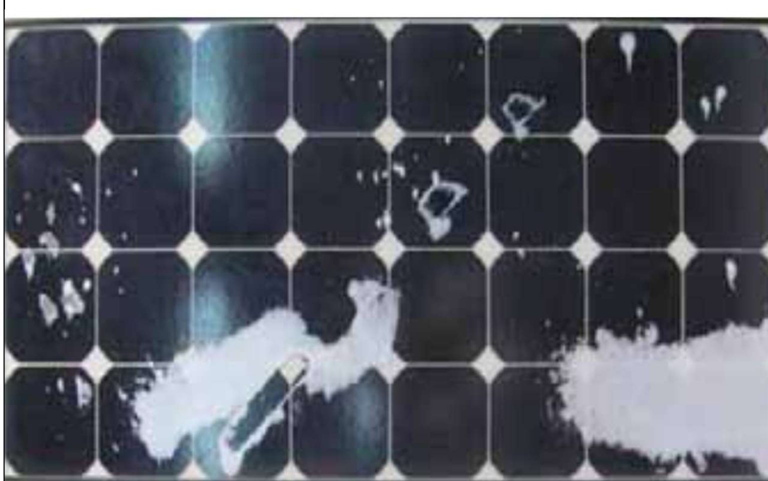
<table>
<tr><td>Component
Defect</td><td colspan="5">Module
Metallisation discolouration/corrosion</td><td>PVFS 1-11vs.01</td></tr>
<tr><td>Appearance</td><td colspan="6">The discolouration and/or corrosion of the cell metallisation and the interconnections is getting visible as a light yellow to dark brown to black discolouration of the electrical parts. Depending on the material combinations corrosion is furthermore noticeable by the presence of galvanic products that may appear powdery, white, light gray, and/or have a yellow, blue, or green tinge. The defect occurs typically at the solder bonds, on the cell gridlines/fingers or the cell/string interconnect ribbons. It is very often observed together with other failures like delamination and discolouration of the encapsulant and sometimes with burn marks. Under certain circumstances corrosion is more visible near cell edges. Dark areas at the cell borders of the EL images can here highlight the diffusion of moisture through the rear side of the module and the gaps between the cells and the subsequent front side cell corrosion starting from the edges.</td></tr>
<tr><td>Detection</td><td colspan="6">VI, (EL, IV)</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="6">The corrosion/oxidation of the metallisation is caused by the presence of moisture and acidity in the encapsulant, as e.g. acetic acid, a degradation product of the mostly used encapsulant EVA or remaining crosslinker (peroxides). Acetic acid has a corrosive effect on the cell metallisation and the cell interconnect. The ingress of moisture caused by an ongoing delamination process leads together with the oxygen to a further acceleration of the corrosion. Corrosion can be caused by a poor manufacturing process (e.g residual crosslinker due to a too short lamination process; imperfections in cell soldering) or the choice of poor materials (low corrosion resistance of tin-based coating of copper ribbons, high water permeability of back sheet and/or encapsulant materials). Environmental factors can accelerate the corrosion (e.g ammonia, salt, humidity, temperature). For these reasons, corrosion is more frequent and severe under hot and humid climates or in agriculture or maritime environments. Discolouration can be also related to non-corrosive processes like a discolouration due to light-sensitive solder flux residues on the ribbon.</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">The metallisation, and/or interconnect, corrosion leads to an increased series resistance and therefore losses in module performance. The power loss is less pronounced for modules with metallisation discolouration without corrosion. The defect does not automatically pose a safety issue. Locally increased series resistance leads to current mismatch. If the mismatch is getting significant, it can trigger the bypass diode and cause further power loss of the PV module.</td></tr>
<tr><td>Safety:</td><td colspan="2"></td><td>Performance:</td><td colspan="2"></td></tr>
<tr><td rowspan="2">Mitigation</td><td colspan="2">Corrective action</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.</td></tr>
</table>

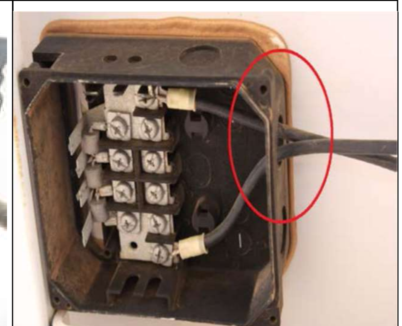
EXAMPLES (page1)			PVFS 1-11vs.01
Examples 1-3			
	Discolouration due to corrosion or to light-sensitive flux residues on the ribbon.	Discolouration due to corrosion on the ribbon. [SUPSI]	String interconnect corrosion. [Köntges17]
Severity	(green hexagon) · 1	(green hexagon) · 1	(green hexagon) · 1 2
Examples 4-6			
	Cell interconnect corrosion. [Köntges17]	Modules with light Ag finger oxidation after 5 years in the field. [Yang19]	Severe oxidation/corrosion and burn marks on the Ag fingers, busbars, and interconnects of modules after 25 years. [Yang19]
Severity	(green hexagon) · 1 2	(green hexagon) · 2	e · 2 3 4
Examples 7-9			
	Corrosion seen as red, green and black discolouration in the string interconnect. [Yang19]	Busbar corrosion and delamination at the edge. [SUPSI]	Glass/glass module showing delamination and subsequent corrosion. [Köntges17]
Severity	e e · 2 3 4 5	e · 3 4 5	e e · 3 4 5

<table>
<tr><td>Component
Defect</td><td colspan="4">Module
Glass corrosion or abrasion</td><td>PVFS 1-12vs.01</td></tr>
<tr><td>Appearance</td><td colspan="5">The degradation of the glass front layer is getting visible as a homogenous or heterogeneous change in colour and transparency of the glass. The affected glass surface can appear hazy or milky and in some cases also rougher compared to the non-degraded module/module area. Increased susceptibility to soling could be observed.</td></tr>
<tr><td>Detection</td><td colspan="5">VI, (IV)</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="5">To optimise the efficiency and appearance of a PV module most manufacturers apply some anti-reflective coatings (ARC), anti-soiling coatings (ASC) or multilayer coatings on the front of their modules. 1-3% more power can be obtained by these techniques respect to module with uncoated glass. Corrosion or abrasion of these layers can however, reduce or vanish the effectiveness of these coatings. Glass corrosion is caused by atmospheric humidity in combination with gases or particles present in the atmosphere (e.g. pollutants, salt, ammonia) and the glass. It happens for example when water (dew) dissolves some of the sodium ions from the top of the soda lime glass, leading to the production of an alkali base that can then corrode the glass silicate. Glass abrasion or corrosion can be also caused by inappropriate cleaning techniques (mechanical removal techniques, inappropriate cleaning agents) which damage or removes the coatings. Abrasion occurs mostly in the desert, due to the combination of wind, sand and dust which causes abrasion and frosting of the glass surface.

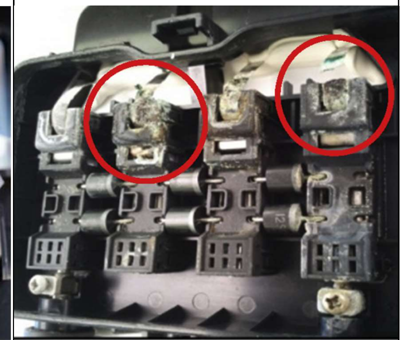
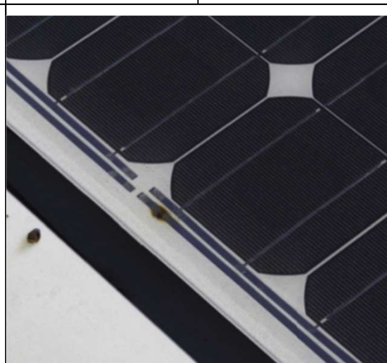
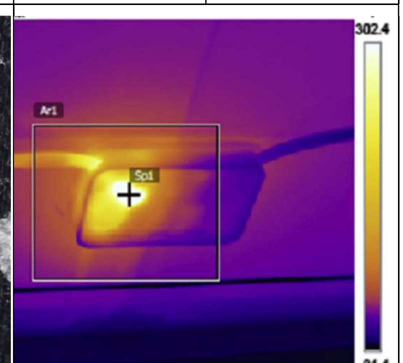
UV or voltage induced degradation effects can further accelerate the degradation of the coatings.</td></tr>
<tr><td colspan="2">Production ■</td><td colspan="2">Installation ☐</td><td>Operation ■</td></tr>
<tr><td rowspan="2">Impact</td><td colspan="5">Corrosion or abrasion of the glass front layer lowers the transmission of the glass, leading to a power loss. The power loss is generally limited to a few percent and is saturating over time except in the case where the soiling susceptibility is significantly increased and larger losses can be observed. Operating and Maintenance (O&M) costs can be affected by this.</td></tr>
<tr><td>Safety:</td><td></td><td>Performance:</td><td colspan="2">2 3 4</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. Depends on the level of performance loss. For extreme environments (e.g. near to mines, cement factories), evaluate cost-effectiveness of replacing modules with lost yield.</td><td colspan="2">Check validity of IEC 61215 certification and BOM, appropriate component selection in function of intended application.</td><td>Regular system inspections.</td></tr>
</table>

EXAMPLES (page1)			PVFS 1-12vs.01
Examples 1-3			
	Zoom of module with hazy glass (homogenous discoloration) due to surface corrosion. [India13]	Zoom of module with hazy glass (heterogenous discoloration) due to surface corrosion. [Petter11]	Hazy glass due to glass corrosion close to frame. [India18]
Severity	2	2 3	2
Examples 4-5			
	Glass corrosion on the front of a mono-Si back-contact module after damp heat 90/90 testing. [Walsh20]		Glass corrosion. [Köntges16]
Severity	3		3 4

Component Defect	**Module** **Defect or detached junction box**		**PVFS 1-13vs.01**
Appearance	The junction box housing and lid appears either defect (weathered, brittle, cracked, warped, melted or burned) and/or detached (open or loose lid, shifted or detached junction box from backsheet). The sealant/adhesive material with which the junction box is attached to the back-sheet can be weathered or appear as yellowed. The sealing components/material around the wire entrance or the lid can be damaged (squeezed, broken, brittle) or completely missing.		
Detection	VI		
Origin	Junction box detachment results from poor fixing of the junction box to the backsheet or use of low quality adhesive. Acrylic or PE Foam tapes were used as junction box attachment material in early years, but they frequently loss stickiness at low temperature and result in detachment. Use of inadequate IP rating junction box may cause water intrusion and subsequent failure. Opened or badly closed j-boxes may due to poor manufacturing process or air pressure caused by high temperature for boxes with no exhaust path. Delamination near a junction box can cause it to become loose. Improper handling or mounting of the modules can be also the cause of damages the j-box, like pulling modules up on the cables before mounting, or missing cable fixing or usage of too short cabling to interconnect modules to a string, causing frequent or permanent mechanical stress on the j-boxes.		
	Production ■	Installation ■	Operation ■
Impact	A defect or detached junction box is causing humidity ingress with **corrosion** of the interconnections, leading to performance losses and increasing risk of electrical **arcing** and subsequent initiation of fire. Furthermore, a loose junction box is putting mechanical stress on the contacts within the junction box, with the risk of breaking them and exposing persons to active electrical components.		
	Safety: f e f e	Performance:	1 2 3 4 5
Mitigation	Corrective actions	Preventive actions (recommended)	Preventive actions (optional)
	Modules with a direct safety risk or a severity of 5 should be replaced or repaired. Regular inspections should be done to monitor the status of the not replaced modules.	Check validity of IEC 61215 certification and BOM. Ground fault detection by inverter or other devices at all time.	Regular system inspections.

Examples 1-3			
	Poorly bonded junction box on the backsheet. [Köntges14]	Open junction box in the field. [Yang19]	Detached junction box from backsheet. [SUPSI]
Severity	f e 1	f e 1 2 3 4 5	f e 1 2 3 4 5
Examples 4-5			
	Left: Missing junction box lid sealing with corrosion of contacts. Right: Good junction box sealing. [India13]		Missing seal or strain relive of module cables, improper cable inlet. [Sinclair17]
Severity	f e	1 2 3 4 5	f e 1 2 3 4 5
Examples 6-7			
	Melted junction box. [TUV Rheinland]	Burned junction box caused by corroded contacts within the junction box. [TUV Rheinland]	
Severity	f e 5	f e 5	

Component Defect	**Module** **Junction box interconnection failure**		**PVFS 1-14vs.01**
Appearance	Not connected, broken, burned, corroded or short circuited parts within the junction box. It can involve solder joints, wires, bypass diodes or tabbing ribbons. The interconnection failure itself could be hidden by the potting material in the junction box and be visible only by removing the potting material. The material can appear as degraded (yellowed, browned, burned or bubbled) due to the heat or arcing occurring in the junction box.		
Detection	IRT, (VI, IV, VOC)		
Origin	Bad contacts or moisture ingress may be the cause of interconnection failures in the junction box. Contacts are either soldered, screwed or inserted (mechanical spring clamping). Bad soldering contacts are caused by low soldering temperature (cold solder point) or chemical residuals of the previous production process on the solder joints. Bad mechanical contacts are caused by loose clamping or screws. Mechanical contacts can get loose due to the thermal cycling of day and night and seasonal changes. Moisture ingress in bad or damaged junction boxes (e.g. adhesion loss, brittled, cracked, missing seal at wire entrance or junction box housing) leads to corrosion of the contacts. Delamination near the junction box can cause it to become loose, putting mechanical stress on the contacts within the junction box and breaking them.		
	Production ■	Installation ☐	Operation ■
Impact	Bad contacts or **corrosion** can cause a high resistance and consequent heating in the junction box. Resistive heating can moreover result in **discolouration** and **burn marks** in the encpasulant/backsheet behind and around the junction box and to **glass breakage**. In the worst case interconnection failures causes a short circuit or internal **arcing** within the j-box. The heat can be detected with a IR camera. In addition to the visual defects, interconnect failures can also lead to significant power losses, which can be detected by measuring the V_{oc} of a module or a string. The measurement can be affected by changing mechanical or thermal stress conditions. Interconnect failures are particularly dangerous because the arcing can initiate fire.		
	Safety: f f e m	Performance:	1 2 3 4 5
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.	Check validity of IEC 61215 certification and BOM. Ground fault detection by inverter or other devices at all time.	Testing of modules with mobile test centre before installation, regular system inspection, installation of arc detection tool.

EXAMPLES (page1)			**PVFS 1-14vs.01**
Examples 1-3			
	Junction box with poor wiring. [Köntges14]	Detached tabbing ribbon due to bad soldering. [Köntges14]	Corrosion failure due to water soaking of the IP65 rated Jbox. [Yang19]
Severity	f	5	f	5	f	2 3 4 5
Examples 4-6			
	Jbox failure due to poor electric connection. [Yang19]	Evidence of loose screw connection inside Jbox with browning of pottant. [Yang19]	Cold soldering of module bussing ribbon to the Jbox connection terminal pad with minor browning of pottant. [Yang19]
Severity	f e m	3 4 5	f	2 3 4 5	f	2 3 4 5
Examples 7-9			
	Overheating due to the poor Jbox interconnect leading to light discoloration and burn mark on front and back side. [Yang19]	Overheating due to the poor Jbox interconnect leading to burn mark and glass breakage. [Yang19]	IR imaging of a hotspot Jbox due to loose electric connection inside. [Yang19]
Severity	f e m	3 4 5	f e m	3 4 5	f e m	3 4 5

<table>
<tr><td>Component
Defect</td><td colspan="5">Module
Missing or insufficient bypass diode protection</td><td>PVFS 1-15vs.01</td></tr>
<tr><td>Appearance</td><td colspan="6">Missing, disconnected, inverted, damaged, open circuited or short circuited bypass diode.</td></tr>
<tr><td>Detection</td><td colspan="6">BYT, (IV, IRT, EL, STM)</td></tr>
<tr><td rowspan="2">Origin</td><td colspan="6">Bypass diodes fail either because they are undersized or because they are exposed to high voltages due to lightning strikes or other high voltage events. In addition to these two reasons, the diodes have a certain ppm of failure rate, that is the nature of the component. For diodes working constantly at high temperatures this failure rate increases. Typically, Schottky diodes are used as bypass diodes in PV modules, but they are very susceptible to static high voltage discharges and mechanical stress. Two main failure modes are observed with bypass diodes: open circuit or short circuit. Short circuit condition occurs when the bypass diode is physical shortened in the junction box, it is mounted the wrong way around or when it has been exposed to high voltages like lightning strikes or static electricity. Open circuit condition occurs when a diode is simply missing, it is not properly connected, a strong current damaged the diode, or it is undersized and not resisting to a continuous current flow.</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">Bypass diodes are mainly used to reduce the power loss caused by partial shading on the PV module and to avoid the reverse biasing of single solar cells higher than the allowed cell reverse bias voltage of the solar cells. In the case of an open circuited diode no current is flowing through the bypass diode and a cell can be reversed with a higher voltage than it is designed for the cell and may evolve hotspots that may cause browning, burn marks or, in the worst case, fire. The problem is that the failure will be not detected until the module is exposed to these risks. A short circuited bypass diode will continuously lower the power production of the module but also of other modules within its string by causing a shift off of their maximum power point. Bypass diode failures sometimes cause the junction box to deform or even burnt due to heat dissipated in the junction box. When the junction box or backsheet are burnt through, the safety issues like leakage current may follow.</td></tr>
<tr><td>Safety:</td><td colspan="2">f</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 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 bypass diode dimensioning, commissioning of system with IRT.</td><td colspan="2">Testing of module bypass diodes with mobile test centre before installation. Regular IRT inspections.</td></tr>
</table>