

EQUIPMENT SPECIFICATION DOCUMENT**PL/EL imager for large tandem Si/PK module**

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TABLE OF CHANGES

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1. PURPOSE

This specification document defines the supply, on behalf of the CEA, of an equipment designated as "PL/EL imager for large tandem Si/PK module". The equipment must be installed at the site "INES" in the building "LYNX4".

The installation work for the equipment will be subject to analysis following the selection of the equipment.

If the technical specifications or requested documents cannot be met, the supplier must clearly specify this in their commercial offer by at least filling out the comment section of Annex 1 of this specification document.

2. DÉFINITION

In this document, the contractor is referred to as "the supplier".

The instructing party is referred to as "CEA".

3. GLOSSARY

- LITEN: Laboratoire d'Innovation pour les Technologies des Energies Nouvelles et les nanomatériaux;
- INES: Institut National de l'Energie Solaire (Bourget du Lac site);
- MTBF: Mean Time Between Failure;
- MTTR: Mean Time To Repair;
- MTBI: Mean Time Between Interrupts;
- FAT: Factory Acceptance Tests;
- SAT: Site Acceptances Tests;
- PL: Photoluminescence;
- Ls-PL: Line scan PL;
- EL: Electroluminescence;
- UVF: Ultraviolet fluorescence;
- PK: Lead halide-based perovskite;
- Voc: Open-circuit voltage under standard test conditions;
- Isc: Short-circuit current under standard test conditions;
- Rs: Series resistance;
- Sun: Photon flux reaching the sample surface under standard test conditions. It is integrated over the solar spectrum from high energy to the band-gap energy of the cell absorber, so it differs for top cell and Si cell;

- PERC: Passivated Emitter and Rear Cell;
- TOPCon: Tunnel Oxide Passivated Contact solar cell;
- SHJ: Silicon Heterojunction solar cell;
- BC: Back-contact solar cell.

4. APPLICABLE DOCUMENTS

The supplier shall comply with the documents and all procedures in force at CEA/GRENOBLE. Below is a non-exhaustive list:

- EQ/CS23-10: Règles applicables aux entreprises extérieures (French version) ;
- EQ/CS23-11: Applicable rules for outside companies (English version).

These documents shall be available for consultation upon request by the supplier.

5. INTERFACE CLIENT - PRESTATAIRE

The technical contacts for the basic and additional services are:

Dr REY Germain

Tel: +33 (0)4 79 79 27 08

Email: germain.rey@cea.fr

6. CONFIDENTIALITY

The supplier undertakes to keep confidential and shall refrain from disclosing to any third party, without written approval from CEA, the whole or part of information and/or knowledge belonging to CEA or any third party, that it may obtain or may have obtained during the service performed on behalf of CEA.

7. TECHNICAL SPECIFICATION

7.1. Description of the Main Function

The imaging system based on scanning imaging must be capable of taking photoluminescence, electroluminescence, UV fluorescence (UVF must be quoted as option) images and conventional photographs (monochrome ok) of full-size PV module (up to 1.4 m x 2.5 m) based on silicon or silicon and lead halide-based perovskite tandem technologies. The module is horizontal and the images are taken from above. In addition, the imager must be capable of applying some of those imaging techniques to cells, strings and layup as defined in the use cases.

For PL/EL, the system must be able to image both top and bottom cell separately; i.e., the result is two images: one of the top cell luminescence and one of the bottom cell luminescence. The acquisition of these images may be sequential or simultaneous. The filtering must prevent capture of bottom/top cell luminescence in the top/bottom cell image. The imaging system must address 1.67 eV material top cell material and should be compatible with a range of 1.55 to 1.73 eV band-gap material for the top cell. The imaging system must address crystalline Si material as bottom cell and as standalone cell (PERC, TOPCon, SHJ, BC). The four imaging techniques can be applied sequentially to a module without hardware or tool change.

7.1.1. Use cases

The system must be capable of addressing the following use cases:

- **Metallised cells**

- Cell Technology: PERC, TOPCon, SHJ, BC, SI/PK Tandem;
- Sample size: half M2 to half G12 cells lined up to cover up to the full length of the imaged field (min. 2.5 m). Imaged field width for cells maybe be reduced to 25 cm, minimum length of field is up to 2.5 m (i.e., the useful length of the scan to produce of an image must be ≥ 2.5 m but the length of the sample might be smaller and even consist in a single half-cell). Cell thickness 90-200 μm ;
- Imaging techniques: line scanning PL before stringing to produce an image combining life time (Voc) image (like conventional PL) and Rs image (like EL but with inverted contrast). Purpose cell quality assessment and detection of single broken finger (not the finger itself but its signature in PL). Mandatory option: only for Si based cells, provide a way to distinguish between Voc issue and Rs issue or using multiple acquisitions in a contactless fashion (width of the field is 25 cm for this option). Conventional photographs;

- **Strings**

- Cell Technology: PERC, TOPCon, SHJ, BC, SI/PK Tandem;
- Sample size: one string up to 15 half M2-G12 in series for line scan PL and EL. If only line scan PL several strings put side by side. Cell thickness 90-200 μm + tab ribbon up to 350 μm on both cell side except for BC;
- Imaging techniques: line scan PL and EL for interconnexion fault detection and disambiguation between Voc issue and Rs issue. Purpose cell and interconnexion quality assessment and detection of single broken finger (not the finger itself but its

signature in PL/EL) Imaged field width for strings maybe be reduced to 25 cm, minimum length of field is up to 2.5 m. Conventional photographs;

- **Lay-up**

- Cell Technology: PERC, TOPCon, SHJ, BC, Si/PK Tandem;
- Sample size: max size 1.4 m x 2.5 m. Stack of Glass (bottom), encapsulant not melted, bussed strings (sunny side down), imaged from top (sunny side down). Alternatively, the layup may consist of a stack of (bottom to up) back sheet / encapsulant / cells sunny side up (imaged sunny side up);
- Imaging techniques: line scan PL and EL for cacks and bussing fault detection. Conventional photographs;

- **Module**

- Cell Technology: PERC, TOPCon, SHJ, BC, Si/PK Tandem;
- Sample size: min size 20°cm x20 cm, max size 1.4 m x 2.5 m. framed or unframed glass-glass, glass-back sheet and lightweight module configurations. Thickness from 0.1 cm to 10 cm;
- Imaging techniques: imaging after production and during stress sequences for various degradation detection and quantification (line scan PL and EL, and UVF) and internal movement of elements (conventional photographs).

The samples are placed horizontally in the imaging system and the images are taken from above the sample. So, the imaging system must be capable of measuring sample sunny side up. The imaged field is 1.4 m x 2.5 m for PL (both Si and tandem), EL, UVF and photographs. Only for Si cell PL, string EL and string PL the useful width can be reduced to 25 cm for disambiguation between Rs and Voc defects or increase image resolution if relevant.

Table 1 – Sample types and dimensions, applicable imaging techniques and purpose summary

Use case overview						
	Sample size (cm) Length, Width, Thickness	LS-PL	EL	UVF (mandatory option)	Photo	Imaging purpose
Cell (metallised)	L:8-250 W:25 T: ~0.01	y	n	n	y	Combined Life time image (Voc image) and metallisation defects detection Rs. Mandatory option: disambiguation Voc/Rs or pure life time image contactless;
String	L:8-250 W:25 T: ~0.1	y	y	n	y	Cracks + Interconnection fault (tabbing) + disambiguation Rs or life time defect;
Layup	L:20-250 W:20-140 T:0.1-0.3	y	y	n	y	Cracks + Interconnection fault (tabbing or bussing) + disambiguation Rs or life time defect, internal movement of elements;
Module	L:20-250 W:20-140 T:0.1-10	y	y	y	y	Various defects or degradations + disambiguation Rs or life time defect, internal movement of elements.

7.1.2. Tool designs and use case illustrations

In the following, several tool designs and how the imager will be used for each case are described. The supplier is free to choose among one of the given examples or propose different design as long as the following criteria are fulfilled:

- Large modules and larges layups (> 1 m long) are loaded by 2 operators carrying the sample by hands, grabbing its long sides. Clear space above and around the sample holder must allow to load and unload the sample without losing contact between operator hands and sample sides;
- Small samples are placed in the centreline of the sample holder, near the edge.

For each of the three examples, working sequences are described for large module / layup, small samples and strings. Strings may be placed parallel or perpendicular to the scanning direction depending on string length, desired feature in the LS-PL or productivity. In addition, a plurality of small samples or strings maybe placed on the sample holder or on a large plate to characterise a batch of samples in a contactless fashion, to increase productivity. In that case the working sequence will be similar to large module / layup case. This batch imaging maybe extended to EL of minimodules series connected as long as the power supply is capable of working in constant current mode.

Figure 1 – fixed camera and lamps, sample holder driven by linear axis – large module / layout

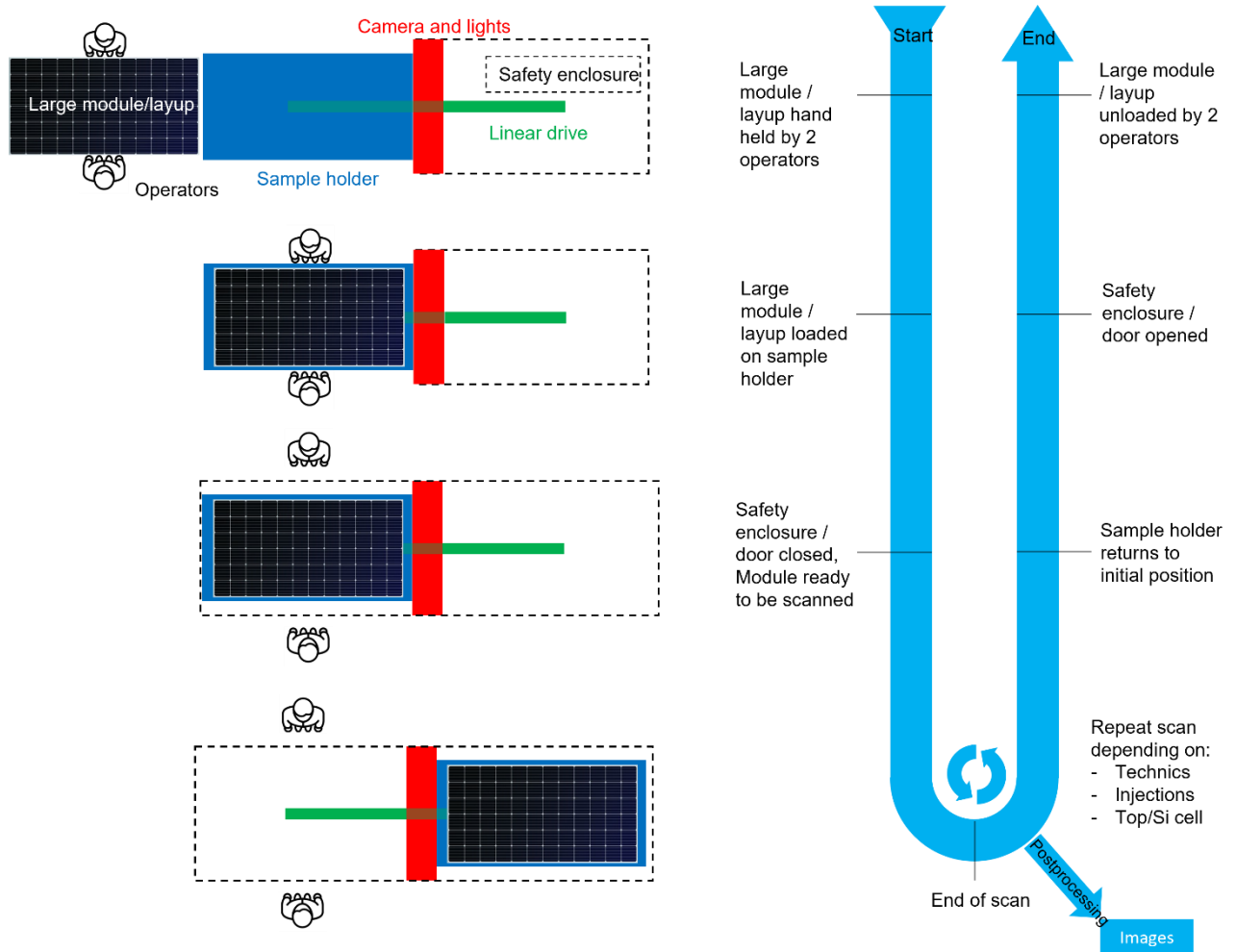


Figure 2 – fixed camera and lamps, sample holder driven by linear axis – small sample

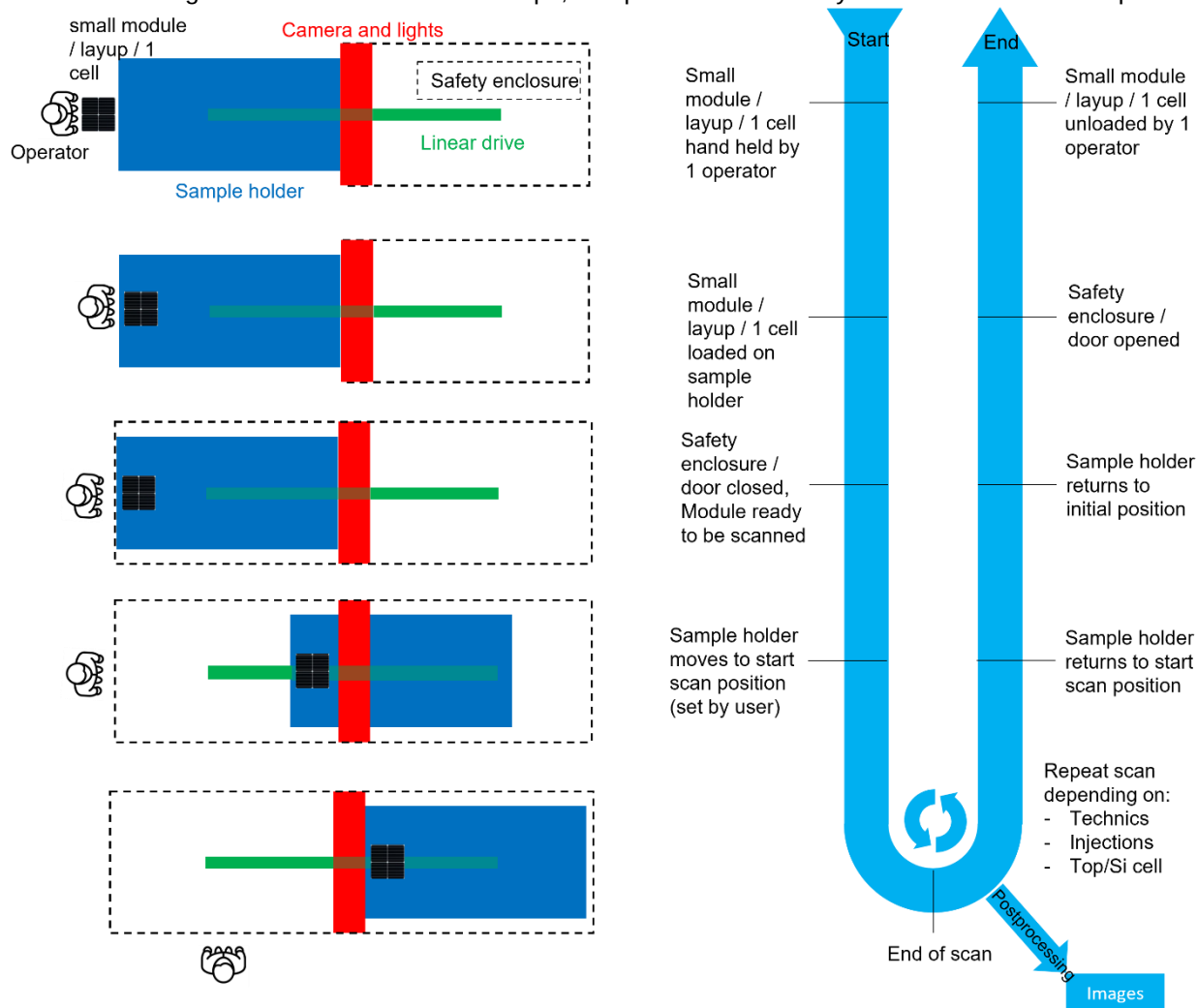


Figure 3 – fixed camera and lamps, sample holder driven by linear axis – string

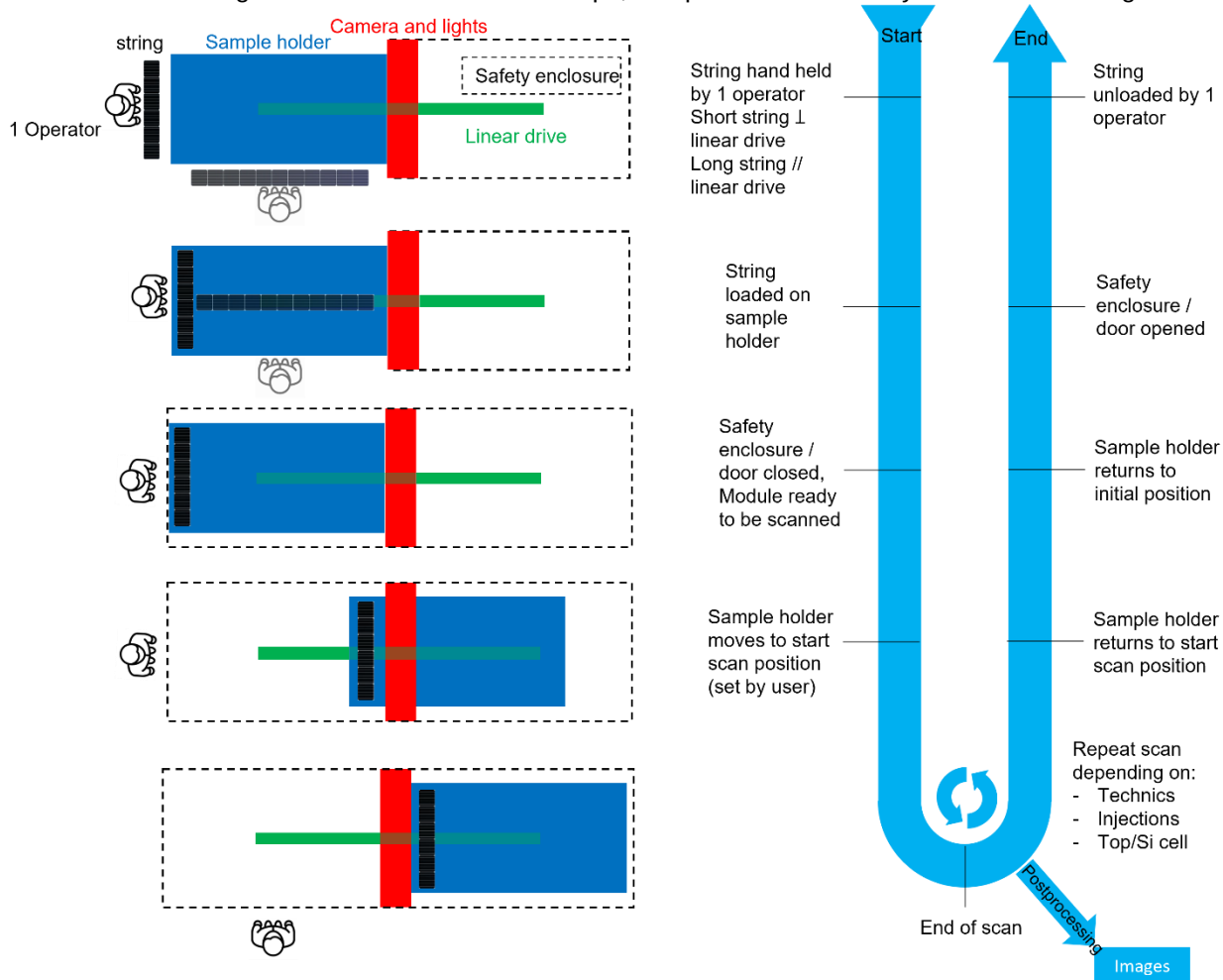


Figure 4 – camera and lamps driven by linear axis, fixed sample holder - large module / layout

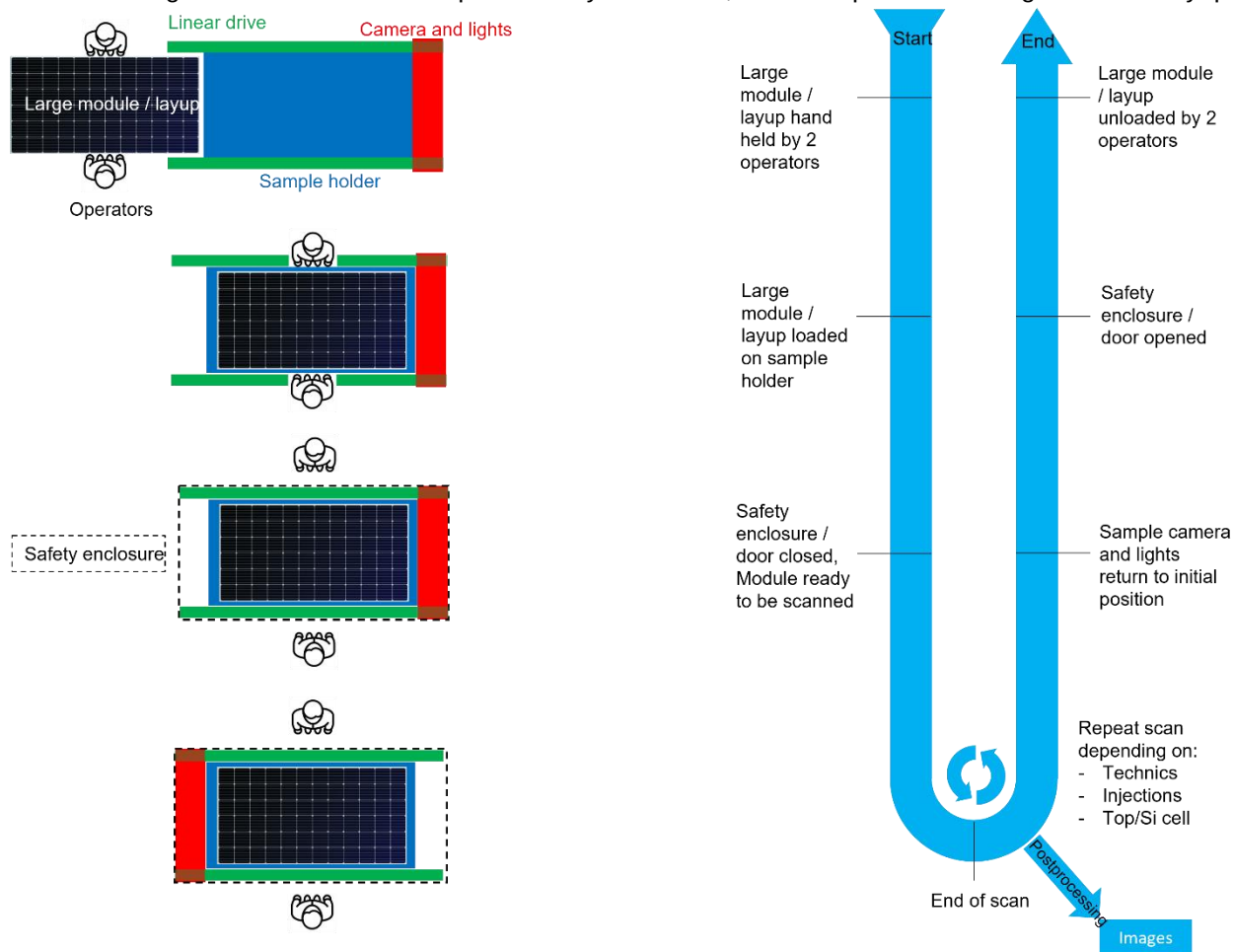


Figure 5 – camera and lamps driven by linear axis, fixed sample holder - small sample

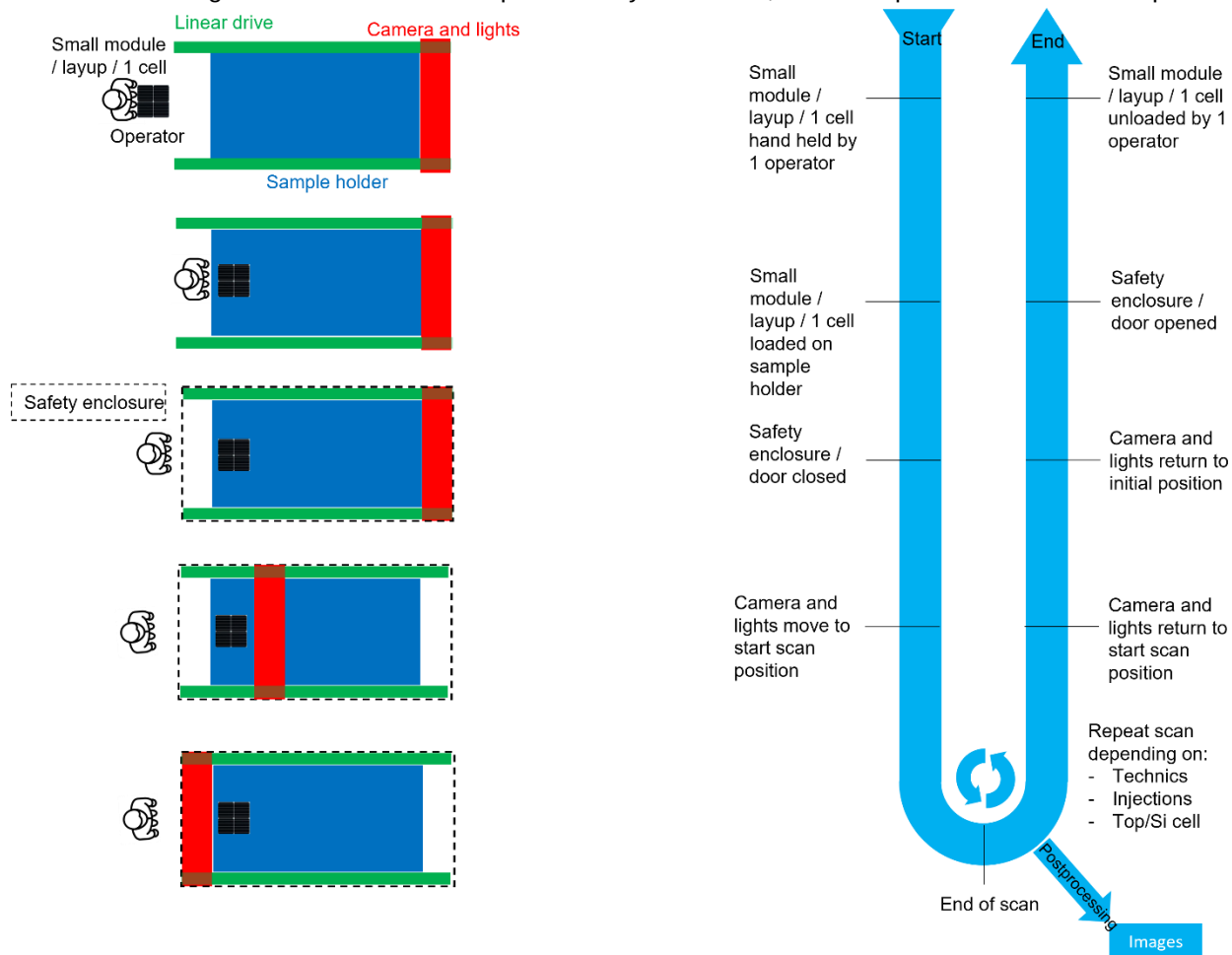


Figure 6 – camera and lamps driven by linear axis, fixed sample holder - string

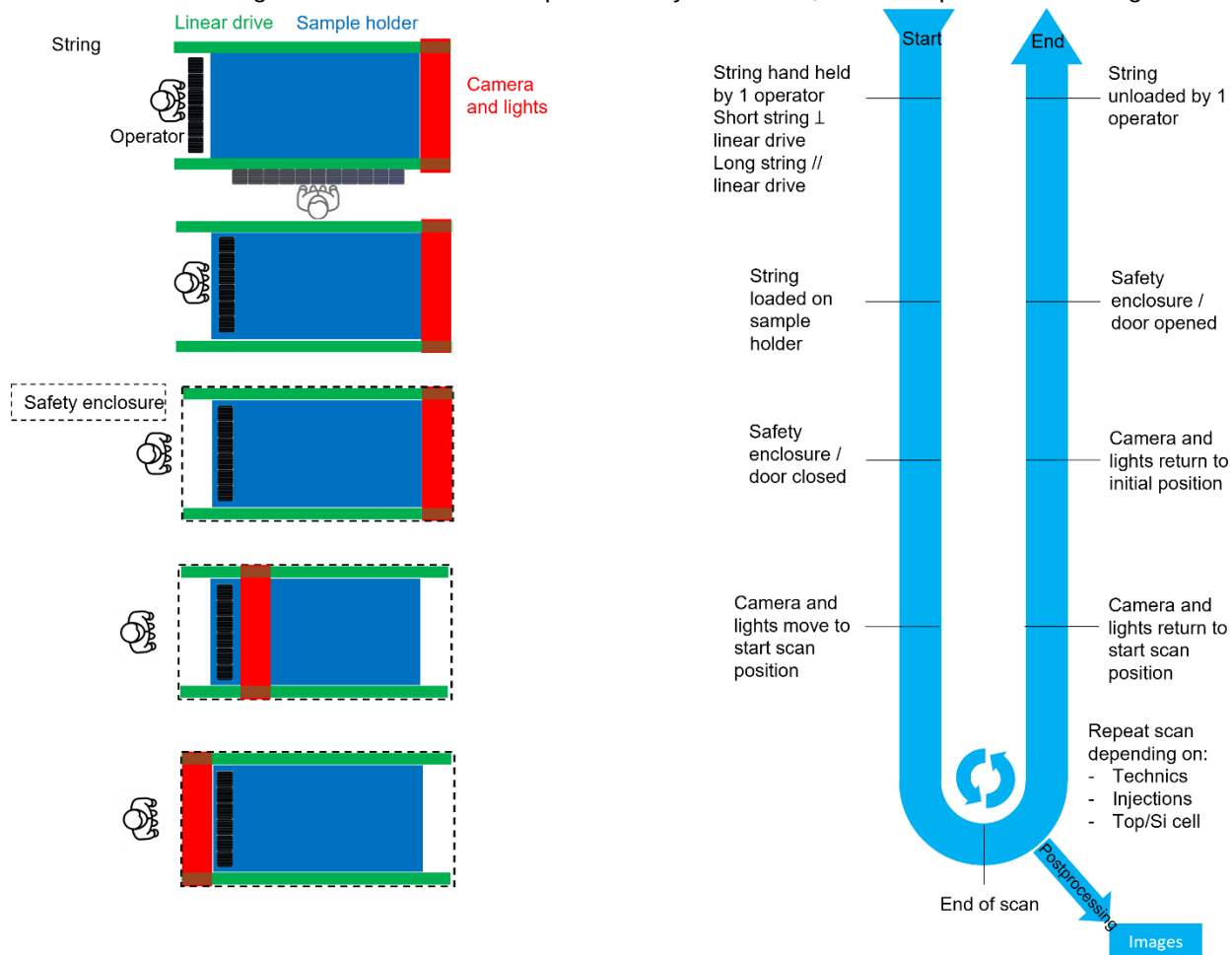


Figure 7 – camera and lamps driven by linear axis, drawer like or rail mounted sample holder - large module / layout

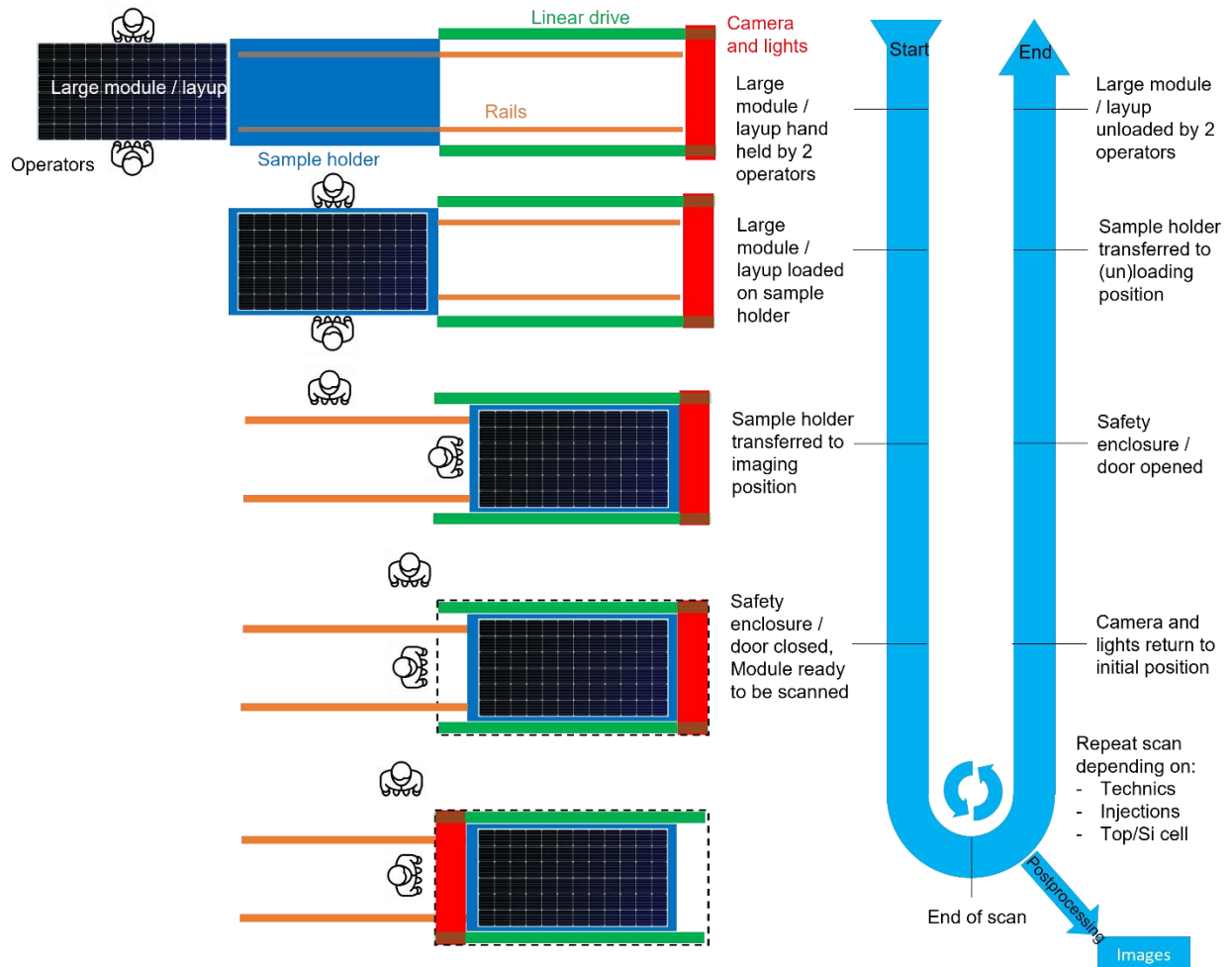


Figure 8 – camera and lamps driven by linear axis, drawer like or rail mounted sample holder – small sample

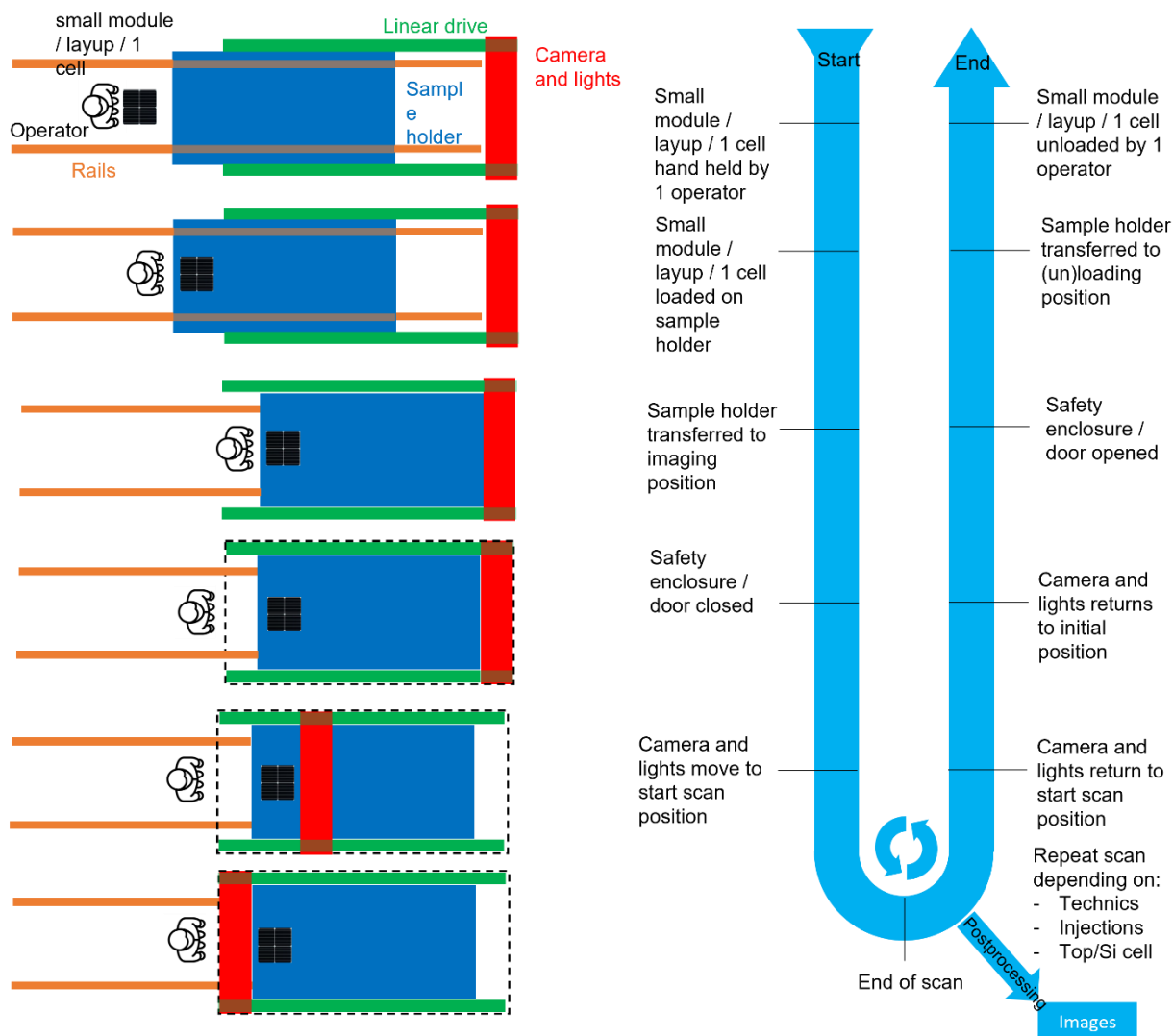
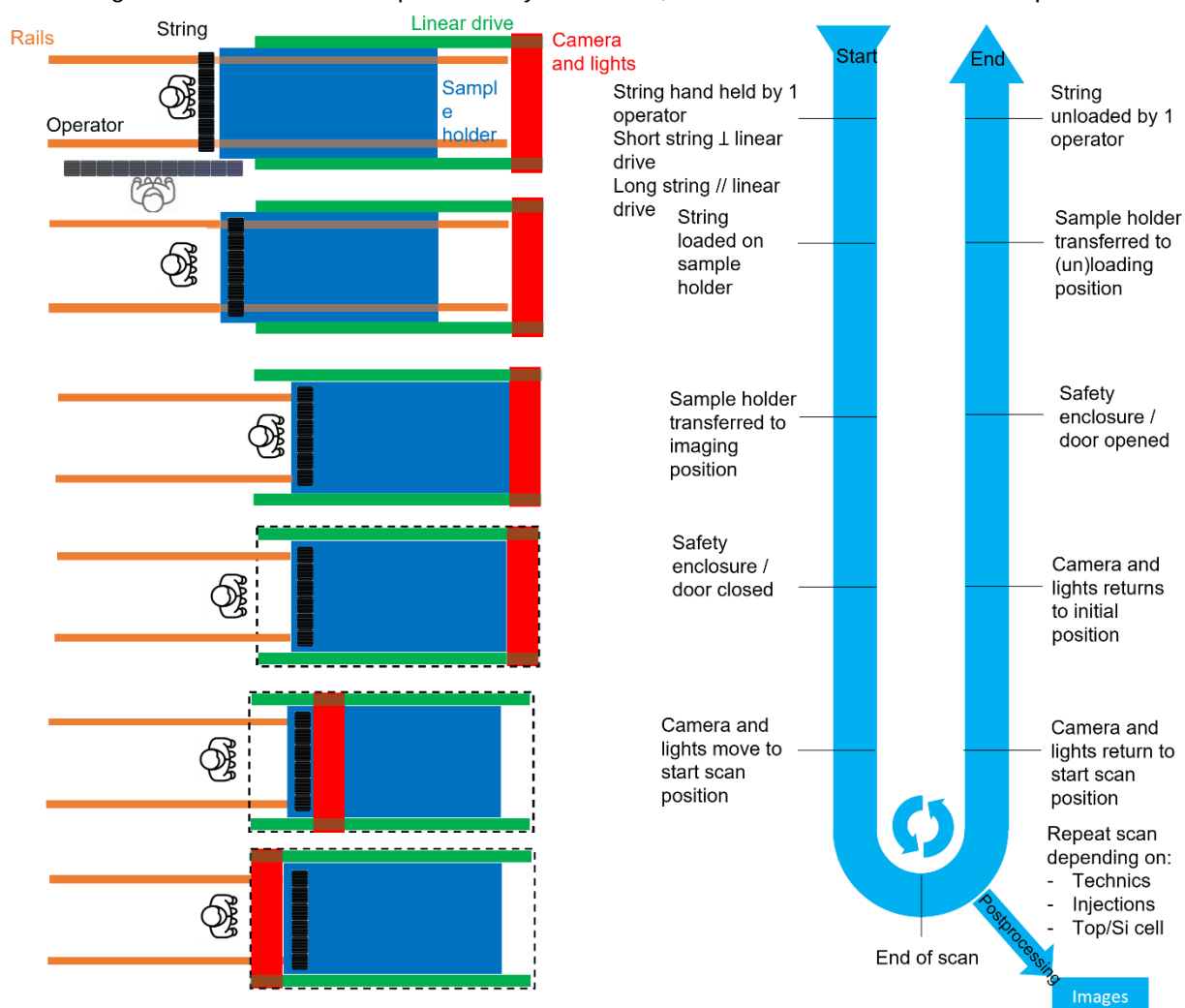


Figure 9 – camera and lamps driven by linear axis, drawer like or rail mounted sample holder - string



7.2. Sub-functions of the Equipment

7.2.1. Sample holder

The imager includes a horizontal sample holder where the various samples described in the use case can be fitted on for imaging

7.2.2. Enclosure

The imager must include a cover to avoid stray light imaging and protect user from radiation, mechanical and electrical risk. The opening of the cover for sample loading and unloading must be interlocked with mechanical, electrical and light power.

7.2.3. Camera

One or several cameras are used to capture the image of the sample.

7.2.4. Filters

PL, EL and UVF may require optical filters to be used in front of the camera to reduce its sensitivity to the band of interest, which depends on techniques and materials

7.2.5. Light source

Lights sources provide material excitation for PL and UVF and allow conventional photography as well.

7.2.6. Current source

Current source injects charges into the photovoltaics device for EL imaging

7.2.7. Linear axis

Scanning imaging relies on a linear axis synchronised with the camera to move the sample with respect the camera and light in order to produce an image

7.2.8. Software

A software allows to control elements of the imager, acquire images, define and command a sequence of image acquisition with different imaging techniques and export images and settings

7.3. List of expected performances

7.3.1. Software

Software must control and record settings of the elements of the imager. Images must be exported in 16-bit tiff and png at least in registered form. For png, scale bar and colour scale maybe included in the image or in separate image if selected by the user. Parameters exported in txt or any text file is mandatory. The software must offer the possibility for the user to select one or several or all (4)

imaging techniques that would be applied to the sample sequentially. The software must offer the possibility to precise the type of sample (Si or tandem) to trigger the proper imaging sequence when EL or PL are selected. The software must offer the possibility to precise the length of the scan (for small samples, there is no need to scan 2.5 m, this allows to save time). Imaging one sample with different techniques, the images must be registered. For tandem, if separate scans are needed for top and bottom cells, the images must be register.

As a mandatory option: for EL and PL, the software should allow to select up to two (at least) excitation intensity (current for EL and photon flux for PL) that will be applied to the sample to generate multiple images (at different injection).

As an option: being able to define a sequence of actions (recipes) in basic language where all part of the imager can be controlled independently + recipe saving and loading

7.3.2. Camera

The imager should be based on a linear camera sensor (1D) or on high aspect ratio camera sensor (2D). The sensor should be an Si based sensor. Time Delay and Integration sensor is preferred. Among Si imaging sensor family, technologies with high quantum efficiency for wavelength above 1000 nm is preferred. Sensor typical quantum efficiency should be >0.1 at 1000 nm. The resolution of the camera should allow to detect single broken finger (not the finger itself but its signature in EL or PL) even for the largest sample (1.4 m wide) and should be:

- at least 4096 pixels along the direction perpendicular to the scan;
- As a mandatory option, if the base sensor has a resolution lower than 8000 pixels (along the direction perpendicular to the scan, the manufacturer must include in the bid an option to upgrade to at least 8192 pixels along the direction perpendicular to the scan.

The sensor bit depth must be at least 12 bits.

7.3.3. Imaging filters

The lens, should be fitted with a filter wheel with remote control operated by the software. The filter wheel must be fitted with the filters needed to image top and bottom cell luminescence signal, UVF images and conventional photographs.

For PL and EL, appropriate filter to image only the band of interest (Dielectric or dielectric + absorptive filter; combined transmittance >0.81 , combined blocking OD4 or more).

For UVF, appropriate filter to image only the band of interest (Dielectric or dielectric + absorptive filter; combined transmittance >0.70 , combined blocking OD3 or more)

The filter wheel must have an extra empty slot for optional filter, thread mount should be specified in the bid. Maximum filter diameter is 50 mm.

All thread are metrics, only acceptable exceptions are lens mounts, filter mounts and pipe fittings.

7.3.4. Light source

Linear LED arrays or expended lasers must be used as excitation source for UVF and PL and as light source for conventional imaging.

For conventional and UVF source the uniformity over the entire width should be better than 20% and repeatability should be better than 10%.

For UVF peak wavelength must be within 350 nm and 380 nm (365 nm peak wavelength preferred). Excitation spectrum short wavelength tail must not extend below 315 nm. Excitation spectrum short

wavelength tail must not be captured by the camera by use of specific filter for UVF imaging if necessary.

For PL excitation source (both top and bottom cell), the intensity should be controllable from 5% to 100% light intensity. The uniformity better than 5% and repeatability better than 3%. For PL the maximum excitation should be at least 1.2 sun equivalent i.e., a photon flux of $3.2 \times 10^{21} \text{ m}^{-2} \cdot \text{s}^{-1}$ for the Si cell and $1.7 \times 10^{21} \text{ m}^{-2} \cdot \text{s}^{-1}$ for the lead halide-based perovskite top cell. For PL and UVF, if the excitation sources are LED, they must be fitted with short pass filter with proper cutting wavelength and OD3 blocking minimum in the imaging spectral range, for lasers sources this filtering might not be needed depending of the long wavelength tail of the laser emission, in that case the manufacturer has to show that this tail is lower than 10^{-4} of the peak intensity in the imaging range. For PL the thermal stability of the light output should be within 5% in the 25-40°C range. If water cooling is needed for the excitation source, the equipment can be connected to our cooling water facility or to a chiller. Both option price and specification may be provided in the bid, at least the chiller option must be provided.

Mandatory option: only for Si based cells, provide a way to distinguish between Rs issue or Voc issue using multiple acquisitions in a contactless fashion: this could be achieved having a narrow illumination over the half-cell for Voc+Rs image (Is-PL) and near uniform illumination at half-cell level (equivalent to ~ 25 cm x 25 cm because of scanning) for the Voc image (like conventional PL). This could be also achieved by having a narrow illumination over the half-cell and imaging the illuminated part for Voc+Rs image and near illuminated part for the Voc-Rs image (contactless EL).

For conventional photographs, the choice of the light source is left to the supplier among one of the following:

- the top cell PL excitation;
- the bottom cell PL excitation;
- an additional white LED source.

7.3.5. Current source

Current source specs are based on TDK Lambda GENESYS+ 150-22.5 single phase input, similar current sources are OK as long as specs are similar or better. Choice between several current sources maybe provided as option in the bid. The current source for EL must be able to supply 150 V and 21 A. In constant current mode, maximum line regulation must be no more than 15 mA, maximum load regulation must be no more than 25 mA. Ripple (r.m.s.) must be less than 45 mA.

Connectors at the sample side must be safety female banana plugs fitted in a junction box. The box must be attached to the sample carrier on the side where small samples are loaded without interfering with sample loading or imaging. The position of the EL current source and the junction box must be optimised to reduce lead length of the DC part in order to reduce voltage drop in the leads.

In the software, before starting the EL acquisition, a way must be provided to the user:

- to check for polarity without overly reverse biasing the sample;
- to check that the power supply will operate in constant current for the selected setting of the power supply and the sample being measured.

Option: Crocodile leads or MC4 leads or string contacting pin assembly are optional.

Option: 4 points probe dark IV using the EL current source and setting max current.

7.3.6. Axis

Whether the sample carrier or the camera and light sources are moving for scanning purpose, the repositioning accuracy shall be no more than 500 μm (mandatory option 100 μm) i.e., after imaging the same module 2 times, the image subtraction of the two images shall not reveal difference in position larger than 500 μm (or 100 μm for the mandatory option). This criterion must be fulfilled when using different imaging techniques.

The image is taken once the axis has reached its constant speed phase. Since the sample maximum length is 2.5 m and since the axis needs to accelerate, decelerate and clear out the light sources and camera away from the sample holder for sample (un)loading, it is expected that the axis stroke is >2.5 m.

7.3.7. Sample holder

The sample holder must be designed to fit various samples as defined in the use case. The system must adapt to the various samples geometry and types defined in the use cases and following requirements:

- Sample size from half M2 cell up to 1.4 m x 2.5 m layout / modules;
- Sample thickness ranging from 90 μm to 10 cm;
- Sample holder paid load is 60 kg;
- Clearance between the imaged object plane and any element above the sample (light sources, camera holder...) must be 5 cm minimum. This is mandatory to ensure safe scan of strings contacted with test pin or modules with junction box on the front side. A safety mechanism (e. g., photoelectric transmitter receiver) must prevent that anything placed on the sample holder with an improper height will not collide into the lamps or any elements during the scan;
- Ergonomic design allowing (un)loading of the sample from side of the imager with 1 or 2 operators depending on the sample size as illustrated in the use cases. This implies a structure free space above the sample holder on three side and an appropriate working height of around 90 cm above ground;
- Vertical stiffness should prevent excessive bending when using contacting pins for string measurement to ensure proper contact (up to 5 N per pin up to 24 pins on a 25 cm line at each end of the string);
- Sample holder top surface should be non-conductive and must be non-reflective;
- Sample holder minimum useful working area is 1.4 m x 2.5 m, it is expected to have at least 2 cm free space around the sample so the sample holder minimum dimension is 1.44 m x 2.54 m sample holder maximum dimension is 1.6 m x 3 m.

To address the sample thickness range and put the sample at required height for imaging either one of those solutions are possible:

- the top sample holder has a fixed height (10 cm below imaged object plane) and the samples are placed above spacer plates to bring the sample front surface at the desired height. This solution is a mandatory option. Spacer plates are optional;

- the top of the sample holder has a height adjustable mechanism (like a lift table or plate mounted on lab jacks). This solution is a mandatory option;
- the camera and lamps assembly has a height adjustable mechanism. This solution is an option.

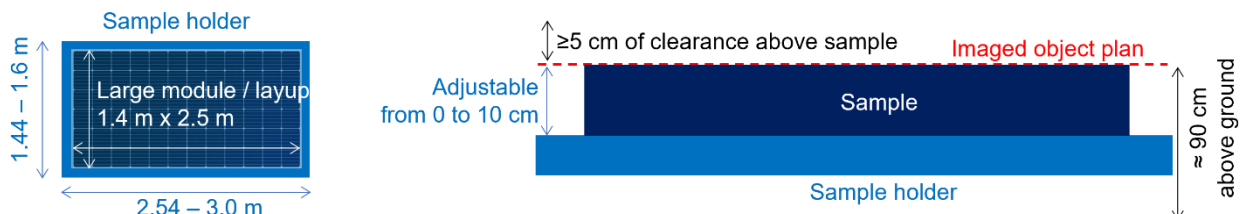
The height adjustment mechanism can be manual or motorised. The accuracy of the mechanism must keep the alignment between the sample, the camera and the light to ensure all part of the sample (up to 1.4 m x 2.5 m) are in the imaged object plane (within depth of field) and that lamp irradiance profile is maintained when using thick or thin samples as long as their front side is placed at working distance. If manual, the height adjustment mechanism is driven by one handle only.

For all cases a height reference must be supplied for efficient positioning of the sample at the working distance.

The sample holder must provide a reference line or edge perpendicular to the scanning direction. Samples maybe aligned with respect to this line / edge to ensure that they appear straight on the images. Maximum deviation must be less than 0.3° between the reference line / edge and the axis direction. The preferred side is the one where small sample are loaded.

Sample holder allowing easy fitting, easy positioning of samples and consistent positioning between samples is preferred. For example, a plate like optical breadboard with multiple threaded holes upon which corners, slides, mounting bases or string contacting pin can be fastened. Any elements on top of sample holder are optional.

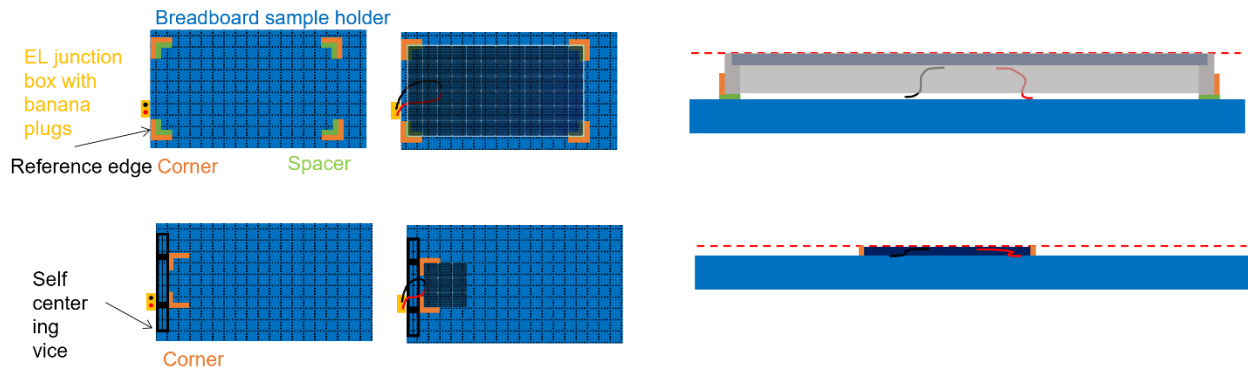
Figure 10 – Dimensions, height and clearance requirement of the sample holder top view and side view



The junction box for EL is fitted next to the sample holder. Shall the sample holder be mobile, this junction box must travel with the sample holder. This junction box should not reach above the sample holder top plate to avoid getting in the way of loading or imaging module

Modules with junction box at the back and framed may require to be lifted above the sample holder top surface to access to the terminal leads. In that case, the module will be mounted on spacers to lift up the module from the top surface of the sample holder and provide enough bottom clearance to access the leads. In that case the maximum of thickness of module + spacer is 10 cm. Shall there be module with 10 cm thickness, lead exit will be from the side or top but not from the back such that extra vertical stroke is not needed beyond 10 cm. The following figure present an example of possible way of sample mounting. Other solutions are ok as long as fitted for purpose.

Figure 11 – Example of sample mounting, top and side view of large framed module with junction box at the back and unframed small module without junction box and lead exit on the side.



7.3.8. Images

Image post processing must encompass none uniformity correction, vignetting correction for all imaging techniques and dark subtraction for PL and EL.

Image aspect ratio distortion must be less than 0.25% i.e., for a 2 m x 1°m sample, the length/width ratio on the image is 2 ± 0.005 . Parallelogram distortion must be less than 0.1% i.e., the alignment between the scanning axis and the camera sensor must be better than 0.06°. Both Image aspect ratio distortion and parallelogram distortion maybe postprocessed to achieve the specified requirement, in this case distortion before post processing must be less than 2% and 1.7% respectively.

For EL and PL, signal to noise ratio SNR50, as defined in the standard IEC TS 60904-13 must be above 50 for a Si module with an open circuit voltage of 0.690 V per cell excited under one sun equivalent (1 sun photon flux for PL and I_{sc} for EL) at scanning speed higher than 0.5 m.s⁻¹.

For PL, using previous sample and image parameters, the PL signal under short-circuit (after dark subtraction) must not exceed 1% of the PL signal under open-circuit condition. This criterion is meant to check for spurious luminescence or excitation light capture in the image.

For PL and EL, image sharpness, as defined in the standard IEC TS 60904-13, must be less than 0.3 mm.

For PL and EL image of module: repeatability in mean signal is +/- 1% over one month period, given that the module is stable (e.g., glass-glass Si module kept in the dark).

Image registration: when taking consecutive images of a same sample (without unloading and reloading the sample) the images must be registered either thanks to the accuracy of the scanning axis and accurate synchronisation between the axis and the camera or thanks to post processing. If post processing is involved, the algorithm must be robust to work proper without the intervention of the user even on sample with highly degraded edges. These images can be acquired with:

- the same technique but different injection or excitation levels (e.g., 1 sun and 0.1 sun PL);
- the same technique but different cells in tandem (e.g., top cell and bottom cell EL);
- different techniques (e.g., 1 sun PL + 0.1 I_{sc} EL + 1 I_{sc} EL + UVF + Photograph of a module).

For all scenarios, the images must be registered. Auto cropping with defined margin could be included as an option.

7.3.9. Enclosure and footprint

Maximum foot print is 7 m long x 2 m wide x 2°m high. The footprint includes all secondary station (e.g., electrical cabinet, power supply, chiller, central unit of PC). The footprint does not include a desk with screen and keyboard to control the equipment. The desk must not be included in the bid.

7.4. Specifications

The expected specifications are gathered in the following table.

Specifications have different rating:

- **F0** = mandatory minimum requirement, must be quoted in the main offer, not negotiable;
- **F0*** = mandatory, must be quoted in the main offer, can be negotiated during the negotiation phase;
- **F1** = Mandatory type of option;
- **F2** = Non-Mandatory type of option.

Note:

Mandatory type of Option: F1 The supplier must obligatorily include an offer with the specified option, otherwise the offer will be considered irregular and eliminated. The CEA reserves the right to decide whether to exercise this option or not, but the price of the option must be clearly stated in the offer. The price of mandatory options will be included in the overall budget for the comparison of offers.

Non-Mandatory type of Option: F2 The supplier has the discretion to propose or not propose the specified option. If the option is not proposed, the supplier will not necessarily be disqualified. The CEA reserves the right to decide whether to exercise the option or not.

Table 2 – Specifications list

Specifications	Value	Rating
Sample		
Configuration	Horizontal, sunny side up	F0
Max size	2.5 m x 1.4 m	F0*
Width	90 µm to 10 cm	F0*
Max weight	60 kg	F0*
Imaging Techniques at full size (= 2.5 m x 1.4 m x thickness 90µm-10cm)		
PL line scan Si cell or tandem bottom Si cell	Cell, string, layup & module	F0
PL line scan tandem top PK cell	Cell, string, layup & module 1.55-1.73 eV band gap energy	F0
EL Si cell or tandem bottom Si cell	String, layup & module	F0
EL tandem top PK cell	String, layup & module 1.55-1.73 eV band gap energy	F0

Specifications	Value	Rating
Photograph	Cell, string, layup & module Monochrome ok	F0
Imaging Techniques at cell width (= 25 cm x thickness 90µm-3m x length 25 to 250 cm)		
PL (line scan with uniform illumination or other)	for disambiguation between Voc and Rs (contactless) on Si half-cells lined up	F1
Software		
Image registration	Consecutive images of same sample	F0
Export image 16-bit tiff		F0
Export image png	w/wo scale bar and colour scale in same or separate image according to user settings	F0
Export settings	Txt or any text file	F0
Select sample type	Si or tandem: triggers appropriate scanning sequence for PL or EL	F0
Control scan length (both start and stop point)	Set scan length 20 cm to 250 cm	F0
Select one imaging techniques	Among PL, EL, UVF, Photo	F0
Select several imaging techniques	Automatically acquired in sequence	F0
Select several imaging techniques and several excitations for EL and PL	Automatically acquired in sequence with at least 2 excitations for EL and PL	F1
Image acquisition recipe	Control each element in basic language	F2
Camera		
Sensor	Si based high aspect ratio	F0*
Sensor	QE > 0.1 at 1000 nm	F0*
Sensor	>= 4096 px width wise	F0
Sensor	>= 8192 px width wise	F0*
Sensor	>= 12-bit depth	F0
Sensor	>= 98% linearity	F0
Imaging Filters		
Filter wheel	Controlled by the software	F0
Filter wheel	One empty slot for an extra optional filter selectable in the software	F0
Filter wheel max filter diameter	50 mm	F0*
EL and PL filters	One for top cell, one for Si cell	F0
EL and PL filters	Dielectric or dielectric + absorptive	F0

Specifications	Value	Rating
EL and PL filters	Combined transmittance >0.81	F0
EL and PL filters	Combined blocking OD4 or more	F0
Light source		
All light sources	Controlled by the software	F0
PL top cell max intensity ≥ 1.2 suns	Photon flux $1.7 \times 10^{21} \text{ m}^{-2} \cdot \text{s}^{-1}$	F0*
PL Si cell max intensity ≥ 1.2 suns	Photon flux $3.2 \times 10^{21} \text{ m}^{-2} \cdot \text{s}^{-1}$	F0*
PL (both top cell and Si)	Intensity control 5%-100%	F0
PL (both top cell and Si)	Uniformity over full width better than 5%	F0
PL (both top cell and Si)	Repeatability better than 3%	F0
PL (both top cell and Si)	Thermal stability 5% in the 25-40°C range	F0
PL (both top cell and Si)	Cooling: chiller	F0
PL (both top cell and Si)	Cooling: cooling water facility	F0
PL (both top cell and Si)	Light source filtering if required: tail in the imaging range below 10^{-4} of peak light source intensity	F0*
Photograph	PL Top excitation source; Or PL Si excitation source; Or extra white LED line	F0
EL current source		
Current source	Controlled by the software	F0
DC power output	supply 150 V and 21 A	F0*
CC mode	Max line regulation 15 mA	F0*
CC mode	Max load regulation 25 mA	F0*
CC mode	Ripple r.m.s. max 45 mA	F0*
In software	Polarity check w/o heavy reverse bias Possibility to bypass the check for reverse bias EL (ReBEL) Check CC mode during EL not CV mode	F0*
Connection interface with sample	Safety banana connectors in junction box	F0
Leads and contactor	MC4 and crocodile For strings	F2
Dark IV	w/ 4-point probes + choosing max current	F2
Choice between several power unit		F0*
Axis		

Specifications	Value	Rating
Repositioning accuracy	500 μm	F0*
Repositioning accuracy	100 μm	F0*
Stroke length	>2.5 m	F0
Sample Holder		
Compatible with all samples in the use cases	cell, string, layup and module	F0
Sample size	Half M2 up to 1.4 m x 2.5 m	F0*
Sample thickness	90 μm to 10 cm	F0*
Sample holder size	Length 2.54 m to 3.00 m Width 1.44 m to 1.60 m	F0*
Payload	60 kg	F0*
Clearance above imaged object plane	≥ 5 cm	F0
Anticollision safety mechanism		F0
Ergonomic	Loading large module with 2 operators handling the long sides of the module Loading sample in the centreline of the sample holder	F0
Height of imaged object plane	≈ 90 cm above ground	F0
Sample holder stiffness	Compatible with the use of string contacting pin (5 N per pin up to 24 pins)	F0
Sample holder top surface	Non-conductive and non-reflective	F0
Height adjustment of sample / camera	Fixed sample holder and camera: use of spacers Height adjustable sample holder Manual with one handle or motorised	F1
Height adjustment of sample / camera	Height adjustable camera and lamp	F2
Height reference	To place the sample at the imaged object plane (in focus)	F0
Reference edge	Perpendicular to scanning direction $\pm 0.3^\circ$	F0
Images		
Post processing (all imaging techniques)	Non-uniformity correction vignetting	F0
Post processing (PL and EL)	Dark subtraction	F0
Distortion: aspect ratio	< 0.25% < 2% in raw image if corrected in postprocessing	F0

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Specifications	Value	Rating
Distortion: parallelogram	< 0.1% (< 0.06°) < 1.7% in raw image if corrected in postprocessing	F0
Signal to noise ratio	SNR50 > 50 for PL at 1 sun and EL at Isc for Si module of 690 mV/cell scanned > 0.5 m/s	F0
Spurious signal and excitation light filtering out in PL	1 IBC Si cell mini module of 690 mV/cell: PL intensity at 1 sun under short-circuit ≤ 1% PL intensity at 1 sun under open-circuit	F0
Image sharpness of EL and PL	≤ 0.3 mm	F0*
Image registration	Images acquired from the same sample (not repositioned on the sample holder)	F0
Repeatability in mean signal for PL and EL image of Si module	±1 % after 1 month. For stable Si glass module kept in the dark.	F0
Enclosure		
Light tight		F0
Doors interlocked		F0
Ergonomics	Do not impede module loading	F0
Footprint		
Length	≤ 7 m	F0*
Width	≤ 2 m	F0*
Height	≤ 2 m	F0*
Specifications	Value	Rating
UVF	Module only	F1
	Excitation peak 365 nm (350-380 nm ok)	
	Intensity control 10%-100%	
	Uniformity over full width better than 10%	
	Repeatability better than 20%	
	365 nm preferred (350-380nm ok) no tail below 315 nm	
UVF filters To block excitation light	Light source filtering if required: tail in the imaging range below 10 ⁻⁴ of peak light source intensity or OD3 filtering	
	Dielectric or dielectric + absorptive	
	Combined transmittance >0.7	
	Combined blocking OD3 or more	

7.4.1. Hardware & Equipment Specifications

In this section, we describe the expected technical performances of the equipment. The conditions under which the target and tolerance will be verified must be clearly specified. If the test conditions proposed by the CEA are not acceptable or sufficient for the equipment manufacturer, the manufacturer may propose alternative test conditions. These alternatives should be clearly documented and agreed upon by both parties to ensure a comprehensive and fair evaluation of the equipment.

Note that these tests may require to control the subfunctions in a way that is fairly different from the intended use in the equipment, e.g., test camera linearity may require to have EL power supply on and take an image but without scanning. The supplier must ensure sufficient control of subfunctions to be able to perform proposed test, that control may not be included in the software for standard user.

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Table 3 – Specifications and test conditions for the hardware and equipment

TEST #	SPECIFICATIONS			PROPOSED TEST CONDITIONS				
	Acceptance Criteria	Equipment Expected Target	Equipment Target Tolerance	Test Condition	Sample Type/Format (Specify who provide them)	Number of Test Samples	FAT or SAT	Test medium (specify who provides it)
G-1	Equipment dimension	$\leq 7 \text{ m} \times \leq 2 \text{ m} \times \leq 2 \text{ m}$	Max +2 cm	NA	NA	NA	FAT	10 m measuring tape CEA
E-1	Power supply	400 V tri or 230 V, f=50 Hz	V: -10%+6% f: $\pm 5 \%$	Depends on local grid spec	NA	NA	FAT	Check local grid spec Check data sheets of electricity powered units the supplier
E-2	Compressed air	$\leq 7 \text{ bar}$	NA	If any	NA	NA	FAT	the supplier
E-3	Water cooling	NA	NA	If any	NA	NA	FAT	the supplier
Sa-1	CE plate	Riveted on frame	NA	NA	NA	NA	FAT & SAT	Visual check
Sa-2	Safety enclosure	Interlocked	NA	Try acquisition with door open Try open door with excited sample or moving axis	NA	Each door ones	FAT & SAT	NA
Sa-3	Safety enclosure	Light tight	NA	Light on at 100% (top cell exc.) not visible from outside in the dark	NA	NA	FAT & SAT	Visual check
C-1	Camera sensor high aspect ratio	$\geq 4:1$	NA	From data sheet	NA	NA	FAT	Check data sheet the supplier
C-2	Camera sensor QE	> 0.1 at 1000 nm	> 0.08 at 1000 nm	From data sheet	NA	NA	FAT	Check data sheet the supplier
C-3	Camera sensor px width	$\geq 4096 \text{ px} / \geq 8192 \text{ px}$	NA	From data sheet	NA	NA	FAT	Check data sheet the supplier

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SPECIFICATIONS				PROPOSED TEST CONDITIONS				
TEST #	Acceptance Criteria	Equipment Expected Target	Equipment Target Tolerance	Test Condition	Sample Type/Format (Specify who provide them)	Number of Test Samples	FAT or SAT	Test medium (specify who provides it)
C-4	Camera sensor bit depth	≥ 12 bit	NA	From data sheet + counts of saturated image	Any	1	FAT	Check data sheet the supplier Computer must have ImageJ software installed
C-5	Camera sensor linearity	100%	98%	See C-5 note	1 cell module IBC	1	FAT	CEA
F-1	Filter wheel slot	≥ 5 slots Minimum 1 empty	NA	From data sheet and visual check	NA	NA	FAT	Check data sheet the supplier and visual check
F-2	Filter wheel filter diameter	≤ 50 mm	≤ 52 mm	NA	NA	NA	FAT	Calliper CEA
F-3	PL filter blocking of excitation light source (both top and Si cell excitation)	OD4	image intensity w / image intensity w/o ≤ 1%	PL Light on 100% No scan, non-luminescent black target, comparison image intensity w vs w/o filter, dark corrected	non-luminescent black target e.g., Thorlabs BKF12	3	FAT	Thorlabs BKF12, CEA
L-1	Top cell excitation maximum photon flux	$1.7 \times 10^{21} \text{ m}^{-2} \cdot \text{s}^{-1}$	$1.56\text{-}1.98 \times 10^{21} \text{ m}^{-2} \cdot \text{s}^{-1}$	Light on 100% No scan, sensor centred in light beam	NA	3	FAT & SAT	See L-1 note
L-2	Si cell excitation maximum photon flux	$3.2 \times 10^{21} \text{ m}^{-2} \cdot \text{s}^{-1}$	$2.93\text{-}3.73 \times 10^{21} \text{ m}^{-2} \cdot \text{s}^{-1}$	Light on 100% Same as L-1	NA	3	FAT & SAT	See L-1 note

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SPECIFICATIONS				PROPOSED TEST CONDITIONS				
TEST #	Acceptance Criteria	Equipment Expected Target	Equipment Target Tolerance	Test Condition	Sample Type/Format (Specify who provide them)	Number of Test Samples	FAT or SAT	Test medium (specify who provides it)
L-3	Top cell excitation control 5-100%	5-100%	5-100% linearity $\pm 3\%$ above 10% power	Light on min to 100% Measurement at 6 power intensity Same as L-1	NA	3 for each intensity	FAT	See L-1 note
L4	Si cell excitation control 5-100%	5-100%	5-100% linearity $\pm 3\%$ above 10% power	Light on min to 100% Measurement at 6 power intensity Same as L-1	NA	3 for each intensity	FAT	See L-1 note
L-5	PL Excitations uniformity over full width (both PL light)	uniform	$\pm 5\%$	Same as L-3 but sensor placed at w = 5, 35, 105 and 135 cm parallel to reference line of sample holder	NA	3 for each intensity and spot	FAT	See L-1 note
L-6	PL Excitations repeatability (both PL light)	repeatable	$\pm 3\%$	Use results from L1-L5	NA	NA	FAT	See L-1 note
L-7	UVF excitation control 10-100%	10-100%	10-100% linearity $\pm 15\%$	Light on, min to 100% Measurement at 6 power intensity Same as L-1	NA	3 for each intensity	FAT	UV radiometer CEA
L-8	UVF excitation uniformity over full width	uniform	$\pm 10\%$	Same as L-3 but sensor placed at w = 5, 35, 105 and 135 cm parallel to reference line of sample holder	NA	3 for each intensity	FAT	UV radiometer CEA
L-9	UVF Excitations repeatability	repeatable	$\pm 20\%$	Use results from L7-L8	NA	NA	FAT	UV radiometer CEA

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SPECIFICATIONS				PROPOSED TEST CONDITIONS				
TEST #	Acceptance Criteria	Equipment Expected Target	Equipment Target Tolerance	Test Condition	Sample Type/Format (Specify who provide them)	Number of Test Samples	FAT or SAT	Test medium (specify who provides it)
L-10	UVF Excitations wavelength	365 nm	350-380 nm, no tail below 315 nm	From data sheet	Any	1	FAT	Check data sheet the supplier
P-1	EL DC power output	150 V 21 A	120 – 180 V 19 – 25 A	From data sheet + multimeter	OC and SC	1	FAT	Multimeter CEA
P-2	CC mode Line regulation, Load regulation, Ripple r.m.s.	≤ 15 mA ≤ 25 mA ≤ 45 mA	≤ 20 mA ≤ 30 mA ≤ 50 mA	From data sheet	Any	1	FAT	Check data sheet the supplier
P-3	Polarity check	No heavy reverse bias	≤ 20 V/cell	Invert polarity on single cell module Check bypass this feature for ReBEL	Single cell module CEA	2	FAT	Equipment software
P-4	Check CC mode, no CV allowed	Auto check before EL	NA	Set V too low compared to module specifications	Standard module or very high current module to work in CV	2	FAT	Equipment software
P-5	Safety banana plugs	NA	NA	Visual check, lead fitting	banana lead connectors	1	FAT	NA
A-1	Axis repositioning accuracy	500 µm or 100 µm	600 µm or 120 µm	Two consecutives raw photographs of large module and image comparison	Module with sharp edge	3	FAT	NA
A-2	Axis stroke length	> 2.5 m	2.51 m - 4 m	Longest possible photograph of a measuring tape	NA	1	FAT	Measuring tape CEA
H-1	Sample holder size	2.54-3 m x 1.44-1.6 m	±2 cm	NA	NA	NA	FAT	Measuring tape CEA

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SPECIFICATIONS				PROPOSED TEST CONDITIONS				
TEST #	Acceptance Criteria	Equipment Expected Target	Equipment Target Tolerance	Test Condition	Sample Type/Format (Specify who provide them)	Number of Test Samples	FAT or SAT	Test medium (specify who provides it)
H-2	Sample holder payload	60 kg	>58 kg	From data sheet	Any	1	FAT	Check data sheet the supplier
H-3	Sample thickness	90 µm to 10 cm	0-11 cm	Adapted to solution	1 cell and 10 cm thick minimodule	1	FAT	10 cm thick module CEA
H-4	Clearance above sample	> 5 cm	> 5 cm	5 cm thick foam on top of large module, must go through scan without crashing	Large module	1	FAT	5 cm thick foam
H-5	Height of imaged object plane	≈ 90 cm above ground	85-100 cm	NA	NA	NA	FAT	Measuring tape CEA
H-6	Ergonomic for large module loading	Ergonomic	NA	Loading a large (120 half-cell M6 or larger) module by two operators handling the long sides of the module	Large module	1	FAT	CEA
H-7	Height reference	Provide height of focus	±0.5 mm	EL/PL + UVF + Photographs at reference height z=0 and z = -1, -0.5, +0.5, +1 mm	Si cell	1	FAT	CEA
H-8	Reference edge	90° from axis line	±0.3°	Photograph of square tool aligned on the reference edge	NA	3	FAT	square tool CEA
H-9	Anticollision safety mechanism	Stop scan	N/A	Place foam or soft material above collision height and start scan	NA	3	FAT	Soft material CEA

7.4.1. Image Specifications

If the test conditions proposed by the CEA are not acceptable or sufficient for the equipment manufacturer, the manufacturer may propose alternative test conditions. These alternatives should be clearly documented and agreed upon by both parties to ensure a comprehensive and fair evaluation of the equipment.

Table 4 – Specifications and test conditions for Imaging

TEST #	SPECIFICATIONS			PROPOSED TEST CONDITIONS				
	Acceptance Criteria	Equipment Expected Target	Equipment Target Tolerance	Test Condition	Sample Type/Format (Specify who provide them)	Number of Test Samples	FAT or SAT	Test medium (specify who provides it)
I-1	Non uniformity correction and vignetting	<2%	Including light source: PL 8%, EL 3%, UVF 13% Photo 8%	Imaging a small sample placed at different position along the width, covering full width	One cell IBC minimodule and white sheet target	3 times x 6 position x 2 samples	FAT & SAT	CEA
I-2	EL/PL dark subtraction	0 counts	0.1% of sensor bit depth	EL at OC=0A	Any	3	FAT & SAT	CEA
I-3	Distortion aspect ratio	No distortion	<0.25% in final image <2% in raw image	Image of large module	Large module of known dimension	3	FAT & SAT	CEA
I-4	Distortion parallelogram	No distortion	<0.1% in final image <1.7% in raw image	Image of square tool	NA	3	FAT & SAT	square tool CEA
I-5	Signal to noise ratio	SNR50>50	>50	As defined by IEC TS 60904-13 See I-5 note, scan speed >0.5 m/s	Module with Voc ≈ 690 mV/cell	See I-5 note	FAT & SAT	See I-5 note
I-6	Spurious signal and excitation light filtering	Image at SC = 0% image at OC	SC ≤ 1% OC	Si PL, 1 sun injection, image OC and SC	Module with Voc ≈ 690 mV/cell very low Rs	3x 3 positions	FAT & SAT	CEA

	SPECIFICATIONS			PROPOSED TEST CONDITIONS				
TEST #	Acceptance Criteria	Equipment Expected Target	Equipment Target Tolerance	Test Condition	Sample Type/Format (Specify who provide them)	Number of Test Samples	FAT or SAT	Test medium (specify who provides it)
I-7	Image sharpness EL and PL	≤ 0.3 mm	≤ 0.4 mm	Si PL, 1 sun injection, Si EL Isc injection, See I-7 note	Module with masking tape and calibration bar	See I-7 note	FAT & SAT	See I-7 note CEA
I-8	Image registration	Registered images for same sample not moved on the holder	2 px	Consecutive image of same sample with target, difference image in ImageJ	Module with target	3x 6 positions	FAT & SAT	CEA
I-9	Broken finger identification	allow to detect single broken finger even for the largest sample (1.4 m wide)	(Not the finger itself but its signature in EL or PL)	image of module with broken finger with PL and EL	Module with broken finger	1	FAT & SAT	CEA
I-10	Repeatability of PL and EL intensity	Average recorded image signal (active area) is repeatable over 1 month	$\leq \pm 1\%$	A glass glass Si module is measured PL 1 sun and EL Isc: FAT: every working day during the FAT SAT: every working day for 1 month	glass glass Si module	3 measurements per day. 1 spot if large module, 3 spots if small module	FAT & SAT	CEA

7.4.2. Software Specifications

If the test conditions proposed by the CEA are not acceptable or sufficient for the equipment manufacturer, the manufacturer may propose alternative test conditions. These alternatives should be clearly documented and agreed upon by both parties to ensure a comprehensive and fair evaluation of the equipment.

Table 5 – Software Specifications and associated test conditions

	SPECIFICATIONS			PROPOSED TEST CONDITIONS				
TEST #	Acceptance Criteria	Equipment Expected Target	Equipment Target Tolerance	Test Condition	Sample Type/Format (Specify who provide them)	Number of Test Samples	FAT or SAT	Test medium (specify who provides it)
S-1	Control of subfunction	Automatic control of subfunction for image acquisition	NA	Control: Interlock, Camera, Filter wheel, Axis, PL (top and Si cell) excitation lights, UVF excitation light, Photograph light, EL power supply. Test through acquiring images of module with PL/EL/UVF and photo of Si and Tandem module with different excitations	NA	≥ 2 module x 4 imaging techniques	FAT	CEA
S-2 = I-8	Image registration	Registered images for same sample not moved on the holder	2 px	Consecutive image of same sample with target, difference image in ImageJ	Module with target	3x 6 positions	FAT	CEA
S-3	Export images	16-bit tiff, png at least	NA	Save images in both format and open in ImageJ.	Any	>2 images	FAT	CEA

TEST #	SPECIFICATIONS			PROPOSED TEST CONDITIONS				
	Acceptance Criteria	Equipment Expected Target	Equipment Target Tolerance	Test Condition	Sample Type/Format (Specify who provide them)	Number of Test Samples	FAT or SAT	Test medium (specify who provides it)
S-4	Export setting	At least sample name, type of image, axis start stop speed, excitation or light intensity	In txt or text file	Export setting for several sample and multiple imaging techniques	Any	>2 samples x 4 imaging techniques	FAT	CEA
S-5	Select sample type	Si or tandem to choose appropriate filters and lights	NA	Select on the software and image a tandem module and a Si module	1 Si and 1 Tandem module	2	FAT	CEA
S-6	Set scan length	Being able to define start position and (stop position or scan length)	NA	Image large and small module loaded at different position and adjust the scan length to reduce measurement time	1 large one small module	6	FAT	CEA
S-7	Select one imaging technique	PL, EL UVF or Photo	NA	Acquire one image of a module. Try the 4 techniques one by one	1 Si and 1 Tandem module	1 x 4 imaging techniques	FAT	CEA

SPECIFICATIONS				PROPOSED TEST CONDITIONS				
TEST #	Acceptance Criteria	Equipment Expected Target	Equipment Target Tolerance	Test Condition	Sample Type/Format (Specify who provide them)	Number of Test Samples	FAT or SAT	Test medium (specify who provides it)
S-8	Select several imaging techniques	Among PL, EL UVF or Photo	NA	Select any combination of 2, 3 and 4 techniques and acquire images	1 Si and 1 Tandem module	6 comb. of 2 techs 4 comb. of 2 techs 1 comb. of 4 techs	FAT	CEA
S-9	Option: 2 or more excitations	for EL and PL	NA	If appropriate: repeat S-8 with one and two excitations for EL and/or PL	1 Si and 1 Tandem module	4 tests	FAT	CEA
S-10	Control filter wheel	Empty slot for research purpose	NA	This filter can be selected for any imaging techniques: repeat S-8 using the empty slot for different imaging techniques	1 Si and 1 Tandem module	2 comb. of 2 techs 2 comb. of 2 techs 2 comb. of 4 techs	FAT	CEA

7.4.3. Process Specifications

If the test conditions proposed by the CEA are not acceptable or sufficient for the equipment manufacturer, the manufacturer may propose alternative test conditions. These alternatives should be clearly documented and agreed upon by both parties to ensure a comprehensive and fair evaluation of the equipment.

Table 6 – Specifications and test conditions for imaging process

	SPECIFICATIONS			PROPOSED TEST CONDITIONS				
TEST #	Acceptance Criteria	Equipment Expected Target	Equipment Target Tolerance	Test Condition	Sample Type/Format (Specify who provide them)	Number of Test Samples	FAT or SAT	Test medium (specify who provides it)
M-1	Mini marathon test	Characterise 300 samples	No equipment related issue and no software issue	Up to 10 samples are characterised several times with up to 10 different imaging sequences including one or several techniques; with at least 50 sequences with all imaging techniques and 50 sequences on tandem modules. 300 sequences ran in total. One shut down + start up in the middle of the run No equipment issue and no software issue permitted All image must meet images requirements	≥1 cell ≥4 Si module (large and small) ≥1 tandem	300 sequences	FAT & SAT	CEA

7.4.4. Notes for specifications and test conditions.

C-5: The single cell module is forward biased in CC about I_{sc} . An EL image is taken and the scanning speed is adjusted to get signal 5% of the useful well depth of camera (useful well depth = bit depth – dark counts for typical imaging parameters). If the speed of the axis is limiting, the current might be reduced. 3 images are taken, the scanning speed is reduced to get 20%, 40%, 60%, 80% and 95%. For each speed the average intensity is taken. The results are analysed with the normalised Intensity (arb. u. counts) x scanning speed (cm/s) that should be $1 \pm 2\%$.

L-1: Si based one cell module with an aperture of 1 cm^2 is IV tested at different irradiance 250-1100 W.m^{-2} at standard test conditions and its quantum efficiency is measured. For Si PL, 100% light should give a short circuit current $I = (1.1-1.4) \times I_{sc}$ (@ 1000 W.m^{-2}) temperature correction might be applied according to cell current temperature coefficient. The linearity is tested in the same way. For top cell, the following coefficient is applied

$$\text{coefficient} = \frac{\int_{1.67}^{\infty} QE(E) \times I_{phs}(E) dE}{\int_0^{\infty} QE(E) \times I_{phs}(E) dE}, \text{ with } I_{phs} \text{ the spectral AM1.5 photon flux.}$$

Alternatively, the photon flux can be measured with an integrating sphere ($0.5-2 \text{ cm}^2$ aperture) and calibrated radiometer or photodiode, in that case, this equipment and calibration certificate are provided by the supplier.

I-5: Signal to noise ratio according to IEC TS 60904-13:2018

Images shall be registered exactly on a pixel-by-pixel basis.

Apply forward bias current through the module until the module temperature is in steady state and then sequentially take two EL images, EL_1 and EL_2 , at the same forward bias current as to be used for the obtained image for study, where EL is an uncompressed grey scale pixel array. The data type for calculation shall be casted at a minimum of twice the bit resolution of the captured images using floating point, preferably double precision 64-bit floating point, to prevent numerical errors

Take a background image of a module EL_{BG} , where the module is in open circuit using the same camera and imaging parameters.

The following ratio of signal to noise is used to determine the SNR, averaged for the imaged scene, SNR_{50}

$$SNR_{50} = \frac{\sum_p \left(0.5 (EL_1(p) + EL_2(p)) - EL_{BG}(p) \right)}{\sum_p \left(|EL_1(p) - EL_2(p)| \sqrt{0.5 \left(\frac{2}{\pi} \right)^{-0.5}} \right)},$$

All image operations for images EL_1 , EL_2 and EL_{BG} are done pixel by pixel (p) in the corresponding image arrays, and then summed for determination of the ratio. The signal is defined as the average of both EL images, EL_1 and EL_2 , reduced by the background image EL_{BG} .

The extension of this definition of the SNR to PL image is straightforward.

The target is to achieve at 1 sun or I_{sc} injection $SNR_{50} > 50$ for a Si module with $V_{oc} = 690$ mV/cell and scanning speed > 0.5 m/s. If the module has a different $V_{oc}/cell$, the target in scanning speed or injection may be adjusted according to the coefficient:

$coefficient = e^{-\frac{\Delta V_{oc}}{V_{th}}}$, with V_{th} the thermal voltage (in V) $= 8.617 \times 10^{-5} \times T$ and T the temperature (in K).

I-7: Sharpness measurement according to IEC TS 60904-13:2018

The sharpness (S [mm]) is used as the index of the resolvable object size in the image obtained by a camera, its settings, and the WD. It is the minimum real dimension that still provides a contrast of 50 %. Sharpness is dependent on the pixel dimension, the linear distance on the module sampled by a pixel, and it includes the effects of image blurriness. A method for determining and classifying image sharpness is defined here. Comparisons for quality of module(s) shall be made between images of similar sharpness classes.

The hereinafter described 'V-cut' measurement involves calculation of the intersection angle α and distance r_{50} from two edge lines L_1 , L_2 created by an opaque mask on top of the luminescent surface. To convert pixels into mm, which will be necessary to obtain the value of r_{50} , a conversion factor between millimetres of length on the module and pixels in the image shall be obtained. It can be obtained from an object of known dimension in the image such as a cell or the module. The formulas needed for the sharpness determination are detailed in Formula (1) through Formula (3).

Two edges are created on an EL image of a monocrystalline silicon PV module. This can be achieved with thin metal plates or opaque (e.g., aluminium film) tape over the luminescing region as illustrated in Figure 4. The angle α between both edge lines should be between 3° and 6° . For an example edge length of 10 cm, this corresponds to a distance of about 0,5 cm to 1,0 cm between both edges at the open end. The edge lines run through the local maxima of an edge gradient image G_{Edge} (Figure 5). The Sobel operator discussed in Annex B may be used to determine G_{Edge} , though the Find Edges function in the public domain software ImageJ, or simple linear derivatives may also be used. The middle line L_2 goes from intersection p_0 of L_1 and L_3 to point p_2 , in the middle of p_1 and p_3 . From all plotted EL image intensity values along L_2 , the distance r_{50} is measured from p_0 to that point on L_2 where the image intensity equals the mean between the dark and bright EL intensity plateau (EL_{low} , EL_{high}) as in the example in Figure 6. The line lengths between points p_0 and p_1 , for example, are indicated by p_0p_1 in Formula (2).

$$S = 1,35 \cdot \alpha \cdot r_{50} \quad (1)$$

$$\alpha = \arccos\left(\frac{\overline{p_0p_1}^2 + \overline{p_0p_3}^2 - \overline{p_1p_3}^2}{2 \cdot \overline{p_0p_1} \cdot \overline{p_0p_3}}\right) \quad (2)$$

$$G_{Edge} = \sqrt{G_x^2 + G_y^2} \quad (3)$$

To reduce the measurement uncertainty, this measurement shall be repeated at least five times at different rotation angles and device positions. Finally, S shall be calculated from the median of all individual results, where the angle α is in radians and the length r_{50} , mm on the module surface.

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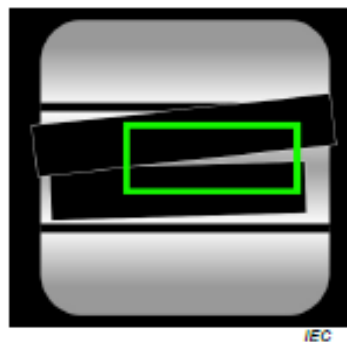


Figure 4 – EL image with introduced two edges using aluminum tape

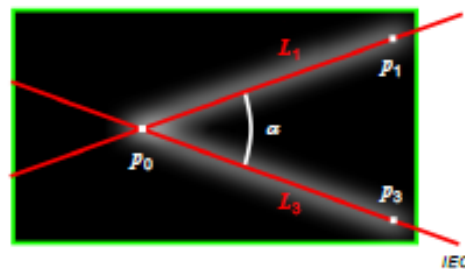


Figure 5 – Edge gradient image G_{Edge} from the Figure 4 EL image's first derivative in orthogonal direction $G_{x,y}$

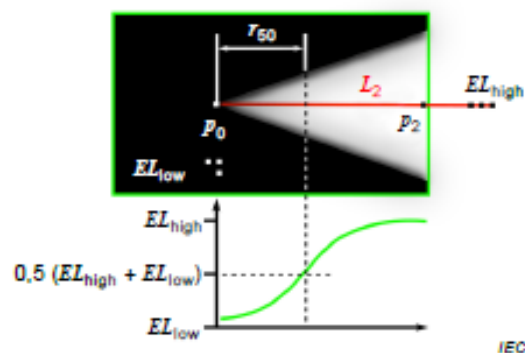


Figure 6 – Excerpt of the EL image of Figure 4 and plot of image intensity values along line L_2

7.5. Computer Specifications

7.5.1. Computer Control

The equipment is controlled from a computer workstation. it shall be set up with a Windows 11 Enterprise Operating System and shall be compatible with the SYMANTEC Endpoint Protection 14.3 antivirus.

7.5.2. Network Connection

The equipment is connected to the CEA network through this PC via a dedicated Ethernet connection. The equipment supplier must ensure that an additional network card is installed in the workstation in case the equipment is connected to the sole available network port.

7.5.3. Instrumentation network cloud

The equipment is connected to a dedicated instrumentation IP network cloud. It follows the principle showed in the following figure:

Main Characteristics of the instrumentation network cloud:

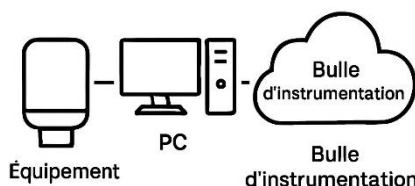


Figure 12 – CEA network connection diagram

- For IT security reasons, there is no internet access or email functionality;
- User session authentication is handled through a CEA Active Directory domain controller;
- Data is uploaded to a shared network storage system;
- Network cloud remote access is restricted to CEA's internal IT management service only.

7.5.4. Connection prerequisites

Prior to network connection, CEA requests that the equipment supplier evaluate the feasibility of:

- Installing CEA's specified antivirus software on the PC (reference available upon request);
- Implementing a process for regular Windows updates with two options:
 - Complete system updates (including all updates);
 - Security-only updates (critical security patches only).

7.5.5. Documentation and procedure

The equipment supplier must document the IT configuration of the equipment for its connection to the CEA network (network interface configuration, protocols to be implemented, ports to be opened, data types, architecture diagram, etc.). The supplier will provide a network connection procedure.

7.5.6. Equipment Supplier IT Contact Availability

Availability of an IT contact from the equipment supplier is requested both prior to and during the network connection process.

7.5.7. Data Export

During operation, if the equipment serves as a data source, data should preferably be exported in flat file formats (TXT, CSV) or office document formats (XLSX, PDF) for deposit in the designated network storage (CEA infrastructure). Images file format should be tiff and png at least.

7.5.8. User Session Management

- Nominal phase:
 - The user session is generic and authenticated through the CEA Active Directory domain controller;
- Maintenance phase:
 - The user session is local, has administrative privileges, and is named with the Equipment manager ID.

7.5.9. Hard Disk Drive Image

Subject to technical feasibility, CEA will create a disk image of the PC and store it on a network resource. In all cases, the equipment supplier must provide a complete system reinstallation procedure and all necessary source files or binary files (removable media, official download links, software licenses, etc.).

7.5.10. Administrator password

CEA requests that the equipment supplier provide the password for the ADMINISTRATOR account. This password will subsequently be managed by the IT service provider under CEA's outsourcing contract.

7.5.11. Remote maintenance

If requested by the equipment supplier and subject to technical feasibility, an external remote maintenance solution may be implemented based on CEA's service offering. For IT security reasons, consumer-grade remote maintenance software is not permitted. Remote maintenance sessions are scheduled and conducted under continuous supervision by CEA personnel. During these sessions, the equipment is physically disconnected from the instrumentation network cloud.

8. WORK ENVIRONMENT, INSTALLATION LOCATION, LIMITS OF SERVICES

8.1. Limits of Services

The limits of Services between CEA and the supplier are the followings:

ITEM	CEA is responsible	Supplier is responsible
Equipment shipping	option	option
Unloading equipment on site and positioning	x	
Equipment setting up on site		x
Hook up	x	
Equipment connection (CA, Electricity, ...)		x
Equipment start-up		x
Cells, strings and modules for FAT & SAT	x	
User training		x
Maintenance training		x

8.2. Environment, Facilities

8.2.1. Environment

The room where the imager will be installed is kept at 23°C +/- 2°C and relative humidity is 45% with an acceptable maximum of 65%

8.2.2. Facilities

The supplier will submit with their offer the requirements for fluids, electrical power, and all other necessary interfaces, and will complete Annex 2 provided with this specification document. If these elements are not known at the time of offer submission as they require further study, the supplier commits to providing this information no later than $T_0 + 4$ months (in accordance with Section9: Timelines).

Available on site:

- Water cooling;
- Compressed air 7 bar;
- Electricity (400 V $\pm$ 10% tri + neutral + ground TNS arrangement & 220 V $\pm$ 10% mono from the 400 V, 50Hz).

Further information about facilities is available upon request

Table 7 – Main relevant facilities for LYNX4 technology platform

Main fluids distribution	Specification for Buliding Lynx4	Note
Cooling water	Piping material: Inox 304L Inlet Pressure: 2.0 bar Inlet Temperature: 18 to 23°C Conductivity: 963 $\mu\text{S/cm}$ pH: 8.5 Point of use Filtration grade: 100 μm	Open loop, cooling power 500 kW
Cold water	Piping material: SS Inlet Pressure: 2.8 bar Inlet Temperature: 6 to 11°C Conductivity: 2778 $\mu\text{S/cm}$ pH: 7.4 Point of use Filtration grade: 100 μm	Cooling power 1.9 MW
Compressed Air	Piping material: Inox 304L Relative Pressure: 7 bar Dew point: -70°C at 9 bar Temperature: 20°C ± 5 Filtration grade: 1 μm and 0.01 μm Oil filtering: 0.1 mg.m^{-3} and 0.01 mg.m^{-3}	

Important note:

Completing Annex 2 will enable CEA to create Piping and Instrumentation Diagrams (PIDs) for fluids as well as the PID for electrical power supply. These PIDs will then be validated by the equipment supplier before hook-up preparation work begins. For simpler equipment, PIDs may not necessarily be required.

Communication Between Equipment and Facilities:

When the equipment relies on certain facilities (such as cooling water, ventilation, compressed air, etc.) for safe operation, the supplier must provide CEA with the following during the design phase:

- The conditions required for proper equipment functioning;
- An analysis of criticality in case of parameter deviations.

This analysis may take the form of an FMECA (Failure Modes, Effects, and Criticality Analysis) or an equivalent method.

Loose of Facility Failure Analysis:

Every potential facility failure—whether isolated or combined with others—must be studied. If a risk is identified, a dedicated section must be included in the documentation.

Safety Signal Integration:

If certain facility parameters could impact:

- The safety of the equipment's process;
- Safe operational mode;
- Overall installation safety.

The supplier must integrate the necessary signals into the safety loop or automation system to enable emergency shutdown or controlled shutdown based on criticality level.

Communication Protocol:

Finally, if the equipment's operation could significantly disrupt the installation's facilities, the supplier must propose to CEA a communication protocol to anticipate and manage these impacts.

8.3. Conditions for performing work on the CEA site

Access to CEA site is strictly regulated. Applicable conditions are described in documents EQ/CS23-10 (Règles applicables aux entreprises extérieures) and EQ/CS23-11 (Applicable rules for outside companies), given in the tender dossier. Same conditions apply to subcontractors if any.

Prevention plan:

CEA will establish, in collaboration with the supplier and any subcontractors, a comprehensive prevention plan for the installation and commissioning of the equipment.

Safety Equipment:

As CEA prohibits the lending of equipment, including safety equipment, the supplier and any subcontractors must provide all necessary safety materials to prevent risks specific to their intervention (PPE, collective protective equipment, etc.). They will ensure the replacement and repair of this equipment and, if applicable, will ensure their personnel are properly trained and aware of its use in accordance with regulations. This equipment must comply with current regulations and have a certificate of conformity.

Collective Safety Equipment:

The supplier and any subcontractors must provide all collective safety equipment aimed at preventing accidents related to the work, such as:

- Marking of work areas;
- Marking of circulation areas;
- Marking of handling areas;
- Marking and installation of barriers around pits and level differences.

They will ensure the installation and removal of this equipment as soon as the service no longer requires the presence of markings.

Specific Access for Deliveries:

Given the access constraints to the CEA site, the supplier must provide a restricted list of individuals authorised to access the CEA:

- For EU residents, 10 calendar days before delivery;
- For non-EU residents, 25 calendar days before delivery.

8.4. Delivery

8.4.1. Delivery and Installation Organization

For the proper organization of delivery and installation at CEA, a packing list must be communicated to CEA at the kick-off meeting or at least 2 months before delivery. This list should include the following information:

- The total net weight of the shipment;
- The number of packages for transporting the equipment;
- The weight and dimensions (length × width × height) of each package;
- The number of support points (legs) and the weight supported by each;
- Any need for specific tools or a forklift for installation;
- The unloading plan.

Whenever unloading requires lifting equipment (forklifts, cranes, etc.), a safety protocol supplementing the prevention plan must be established before the unloading operation.

All delivered materials must bear the order reference and the recipient's name on each item in the packing list.

8.4.2. Supplier Presence

Although CEA is responsible for unloading equipment on site and positioning, The supplier must arrange for all necessary measures to unload and install the equipment (unloading plan and installation plan). **The supplier must be present during the unloading of any equipment requiring special monitoring due to its size, value, or complexity.**

8.4.3. Installation Location

The equipment must be installed at the INES site in the LYNX4 building.

8.4.4. Logistical Constraints

The supplier must consider logistical constraints related to equipment placement (maximum space, weight, access through doors, ramps, stairs, elevators, maximum height, etc.). These details are specified in Annex 1.

8.4.5. Dimensional and Load Constraints:

Maximum package size is 3.9 m in width and 3 m in height 8 m in length.

8.4.6. Packaging and Waste Disposal

The equipment and all its peripherals must be delivered clean and properly packaged. Transport platforms, pallets, and packaging crates must be suitable for the weight and volume of the items to ensure safe transport and avoid any disputes related to improper packaging.

All transport platforms, pallets, and packaging crates must be removed by the supplier (waste disposal from packaging is not handled by CEA).

8.4.7. Delivery Hours

Deliveries will be made between 8:00 AM and 12:00 AM from Monday to Friday.

9. TIMELINE

All the deadlines mentioned below are indicative.

Step	Deadline
Providing information about design not known at time of the bid	$T_0^* + 2$ months
Factory Acceptance Test (FAT)	$T_0 + 6$ months
Equipment delivery at CEA site	$T_0 + 8$ months
Training	$T_0 + 9$ months
Site Acceptance Test (SAT)	$T_0 + 9$ months

* T_0 refers to the date of order notification by CEA.

To facilitate compliance with delivery and acceptance deadlines, the supplier must promptly transmit all annexes required for equipment installation (fluid requirements, electrical power supply, and any other necessary interfaces (Annex 2), hazard identification sheet (Annex 3), equipment consumption data, etc.) or any other necessary elements.

10. QUALITY

For all its activities, the supplier must comply with the requirements of the ISO 9001 standard.

Significant and/or repeated deviations from this specification will be notified to the supplier (via email-anomaly or Improvement Sheet) for corrective action within a specified timeframe. In case of

deviations or unperformed corrective actions, penalties will be applied to the supplier in accordance with the contract.

CEA Grenoble reserves the right to verify the effective operation of the system at any time through quality audits, which may be conducted at the supplier's premises and on the CEA Grenoble site.

Any measurements performed by the supplier for acceptance testing must comply with the requirements of Section 7.1.5 of ISO 9001 (Resources for Monitoring and Measurement). If the supplier subcontracts these measurements, they must be accompanied by a certificate of conformity.

11. SAFETY AND COMPLIANCE

As required in CEA's general purchasing conditions, the supplier commits to treating safety as an absolute priority in the design, preparation, and execution of the services covered by the contract.

The supplier acknowledges and applies the "rules applicable to external companies at the Grenoble centre" provided with the tender dossier.

The supplier, as well as any subcontractors at any level, must comply with all applicable legislative and regulatory provisions regarding safety and environmental protection.

The equipment must comply with current regulations.

The equipment will be CE certified, bear the "CE marking," and be accompanied by a CE Declaration of Conformity (see § 13 Documentation).

Because the equipment is not a catalogue item. The supplier is requested to seek assistance from a French certification body to verify regulatory compliance from the equipment's design phase.

11.1. Hazard Identification

CEA may request the supplier to provide a description of the equipment's residual hazards, including the following information:

- Details about residual hazards for operators;
- Interactions between the equipment and its environment (gas or chemical emissions, electromagnetic fields, noise, etc.)

If hazard identification is required, CEA will make this request no later than during the market launch meeting. The supplier will base this analysis on Annex 3 of the Technical Specification Document: Identification of Residual Hazards.

The supplier must submit this analysis to CEA during the design phase (cf. § 13 Documentation).

11.2. Risks associated to facilities

Please specify risks associated to facilities if any

11.3. Power supply disconnection and separation device

A power supply disconnection and separation device shall be provided on the equipment, for each source of energy of the machine.

11.4. Power supply lockout / tagout device

A power supply lockout / tagout device with dissipation of the residual energy shall be provided on the equipment, for each source of energy of the machine.

11.5. Emergency stop

Emergency stop buttons shall feature protection against unintentional operation. See the example on the side picture.



11.6. "Service" nitrogen or compressed air connection

When the equipment uses compressed air or nitrogen for controlling valves, actuators, and other systems, the machine must be equipped with a general shut-off valve.

This valve may be locked in the closed position using a padlock to allow for equipment isolation (maintenance).

There must be one or more purge devices to dissipate residual pneumatic energy stored in the machine after the main valve is closed. This dissipation must be performed without risk to exposed personnel.

11.7. Risks related to electricity

Generalities

The equipment shall comply with the regulations in force, in particular the following Directives:

- "Electrical Equipment" 2014/35/EU;
- "Electromagnetic compatibility" 2014/30/EU;
- "Restriction of the use of certain hazardous substances in electrical and electronic equipment" (2011/65/EU).

If the equipment is composed of electrical measurement, control and laboratory devices, it shall comply with:

- Standard NF EN 61010-1.

11.8. Presence of an uninterruptible power supply (UPS)

If the whole equipment must be supplied by an uninterruptible power supply (UPS), then this power supply shall be provided by CEA.

The supplier shall give all the required information for product definition (voltage, power, battery life). The supplier shall provide connection terminals on the equipment to connect the uninterruptible power supply.

In the event that only a portion of the equipment is powered by an internal UPS integrated by the manufacturer, the following rules shall be observed:

- An all-pole isolating device shall be installed downstream of the UPS in order to enable maintenance operations;

- If voltage still remains after the master switch of the machine has been turned off, such presence shall be indicated close to the switch;
- All circuits that remain live after switch off shall be marked in orange colour in accordance with standard 60-204.

11.9. Risks related to Chemicals

When the equipment uses chemical products that pose health and safety risks to operators, the supplier must detail in the risk analysis the protective measures implemented during normal, degraded, or maintenance work phases.

11.10. Risks related to handling

For those parts of the equipment requiring handling (pumping units, chamber lids, covers, etc.), in particular during maintenance or installation operations, suitable lifting means shall be provided and described in the safety instructions of the equipment.

Systems integrated into the equipment shall be given preference over removable systems.

11.11. Risks related to artificial optical radiation

These include visible, infrared, and ultraviolet radiation, whether coherent (such as lasers) or incoherent.

The design, implementation, and labelling of the affected equipment must comply with current regulations and standards.

The supplier must provide CEA with information about the artificial optical radiation used in the equipment during the design phase, particularly regarding the risks to users.

11.12. Risks related to noise

As the equipment falls under the definition of a machine, it must comply with current regulations, including Regulation EU 2023/1230.

11.13. Risks related to temperatures

As the equipment falls under the definition of a machine, it must comply with current regulations, including Regulation EU 2023/1230.

11.14. Signalling

As the equipment falls under the definition of a machine, it must comply with current regulations, including Regulation EU 2023/1230.

Residual risks shall be indicated on the machine by means of regulatory hazard pictograms (triangles with yellow background), accompanied by additional text when applicable. In this case, this text shall be written in French.

11.15. Regulatory Inspection

CEA shall have the necessary regulatory inspections carried out by an authorised organisation of its choice, in order to verify that the supplied equipment complies with the regulations.

The Supplier shall remedy any non-conformity in the shortest time possible without being able to claim any compensation. Depending on the severity of the detected anomalies, CEA may decide to suspend the commissioning operations until the problems have been solved (refer to Article 30 of chapter 11 of the General Purchasing Conditions).

11.16. Inspection of the work equipment

The equipment must comply with current regulations, particularly Regulation EU 2023/1230. It must be accompanied by:

- The CE marking of the machine;
- The Declaration of Conformity;
- The instruction manual **in French**, (or at least the safety section in French) including all necessary plans, diagrams, and documents for installation, commissioning, operation, adjustment, assembly, and disassembly.

CEA may arrange for a machine control inspection at the manufacturing site by a certification body of its choice. The report from this manufacturing site inspection must be free of any non-conformities. All remarks made by the certification body must be addressed by the contract holder, who will implement the necessary modifications without requesting any financial contribution from CEA.

In all cases, a second inspection must be conducted after the equipment is installed on-site.

CEA reserves the right to conduct a second inspection after the non-conformities have been resolved.

As the equipment meets the definition of a machine, the design of the safety-related control systems must be carried out in accordance with the EN ISO 13849-1 standard. The contract holder must provide CEA with:

- The list of safety-related control systems (SRP/CS);
- The reasoning followed during the design (e.g., the faults considered, the faults excluded);
- The result of the required performance level;
- The achieved performance level;
- The calculation tool used (e.g., SiStema).

11.17. Regulatory electrical inspection

CEA is attentive to the proper sizing of electrical supplies for equipment connected to its electrical network.

To facilitate proper sizing of the power supply, the supplier must provide CEA with all electrical information for the equipment, including cumulative power ratings determined by calculation (e.g., using the ELIE BT tool).

Once the equipment is installed on-site, CEA will arrange for a regulatory electrical inspection before first commissioning by an accredited certification body of its choice.

12. ENVIRONMENTAL CLAUSES

12.1. Environmental Clause (Material Durability/Facilitating Equipment Maintainability)

The Contract Holder commits to implementing all the provisions described in their environmental proposal, which is an integral part of the contract.

In this context, and in accordance with these commitments, the Contract Holder implements all or part of the following environmental measures during the contract execution:

- To design equipment with robust materials and extended lifespan;
- To propose equipment offering scalability or adaptability (e.g., by adding frames);
- To ensure that the components of the equipment are easily disassembled and repairable;
- To propose training on the use of the Equipment in line with the implementation of the clause.

The Contract Holder remains free to submit any alternative solution within the scope of this clause.

The Contract Holder commits to providing recommendations to extend the lifespan of the Equipment during the contract execution.

13. EQUIPMENT DOCUMENTATION

The equipment supplier commits to provide, no later than before the Site Acceptance Test (SAT), all technical and administrative documentation related to the equipment (non-exhaustive list).

This documentation will include at least:

- The instruction manual written in French, if this is not possible, only the “safety” section of the manual shall be written in French;
- The CE Declaration of Conformity (in accordance with Regulation EU 2023/1230);
- Identification of hazard sources (see Annex 3) and safety instructions. These documents will enable the development of a risk analysis for the equipment, co-constructed between CEA and the equipment supplier (no later than before the SAT);
- The maintenance manual;
- If applicable, technical and installation manuals for all commercial devices, accompanied by their calibration certificates, particularly for measurement sensors;
- The list of spare parts and consumables for routine maintenance, with costs and procurement lead times;
- Process plans and diagrams (assembly, piping, and instrumentation);
- The final design file of the equipment.

14. ACCEPTANCE CONDITIONS

14.1. Reception Breakdown

Reception will consist of two phases:

- Factory Acceptance Test (FAT);
- Site Acceptance Test (SAT).

14.1.1. FAT Phase - Factory Control and Testing

The supplier must propose a procedure for controlling and testing the equipment. This procedure must include the controls and tests requested by CEA (cf. § 7.4).

The controls carried out at the supplier's site will follow this procedure, which must be submitted to CEA for approval beforehand. After approval of the procedure, CEA will indicate the tests it wishes to attend.

At the end of the FAT, a pre-acceptance proceedings record following CEA's formalism is drawn up and signed by both parties. This pre-acceptance proceedings record allows the acceptance of the factory control file and the listing of reservations.

14.1.2. SAT Phase - Control and Testing on CEA Site

The tests to be carried out on the CEA site must be defined by CEA and validated by the supplier.

If remarks were made during the factory reception (FAT), it will be necessary to verify that the corrective actions implemented meet the safety or technical requirements.

The acceptance tests must cover all the specifications of paragraph § 7.4.

Each requirement must be evaluated (compliant/non-compliant/partially compliant), and the results must be recorded.

Before pronouncing the reception, the supplier must submit all the test and control reports carried out during the SAT.

14.2. Acceptance Criteria

Acceptance will be granted if:

- The equipment complies with regulatory requirements;
- The equipment meets all contractual technical requirements (see § 7).

If CEA provides the measurement equipment: Verify the availability of suitable ECME with sufficient precision.

If the supplier provides the measurement equipment:

- Measurements must be performed using compliant ECME;
- The supplier must provide calibration certificates with COFRAC accreditation or equivalent.

14.3. Final Acceptance Pronouncement on Site

A proceedings record following CEA's formalism is then drawn up and signed by both parties. This proceedings record allows the acceptance of the control file and, if necessary, the listing of reservations.

Final acceptance is pronounced when:

- The equipment has been delivered in full;
- Installation, commissioning and start-up are completed;
- Qualification controls and tests have been successfully passed;
- Regulatory compliance has been approved. If applicable, machine compliance according to EU 2023/1230, as per a report issued by a CEA-accredited body, with no non-conformities;
- The complete equipment documentation has been delivered (see §13).

15. TRAINING

The supplier commits to providing the following training sessions. A training certificate will be issued by the supplier, listing the trained personnel and their level of intervention.

15.1. Equipment Operation Training

The supplier commits to providing training on the use of the Equipment for 5 personnel. The supplier will indicate in their offer the number of training days required.

This training will cover, among other topics, sample loading and unloading, equipment operation, and control system handling, data export.

15.2. First-Level Maintenance Training

The supplier commits to providing first-level maintenance training for 3 personnel. The supplier will indicate in their offer the number of training days required.

15.3. Advanced Maintenance Training

The supplier commits to providing advanced-level maintenance training for 2 personnel. The supplier will indicate in their offer the number of training days required.

16. WARRANTY

The equipment is contractually guaranteed for 2 years from the date of acceptance against any defects in material, manufacturing, assembly, and operation, in compliance with the technical specifications of the tender document.

This warranty covers parts (excluding consumables), labour, transportation, and travel.

During the warranty period, the supplier commits to take action for repairs or remote assistance within 4 working days following receipt of an email request for intervention from CEA. These services are performed every day from Monday to Friday, 8 AM to 5 PM.

In case of unavailability, the warranty period is extended by an equivalent duration to the equipment's downtime.

17. MAINTENANCE

In their pricing offer, the supplier will provide a price for a full-service maintenance contract including annual preventive maintenance, unlimited corrective maintenance, and unlimited spare parts

Following adjustments to CEA's maintenance needs, the maintenance contract may be established after the warranty period through negotiations.

18. ELEMENTS TO PROVIDE IN RESPONSE TO THE CONSULTATION

- Comments from the Equipment Supplier on the Equipment Specification Document (see Annex 1, FOR_533_Annexe_1.xlsx);
- Completed characteristics of fluid requirements, electrical power supply, and all other necessary interfaces (see Annex 2, FOR_534_Annexe_2.xlsx);
- Hazard identification sheet (see § 11.1 and Annex 3, FOR_535_Annexe_3.xlsx);
- The cost of preventive maintenance service should be specified;
- Duration and descriptions of planned training sessions;
- Separated mandatory and non-mandatory option quotes (see Table 2 – Specifications list).

Mandatory and non-mandatory Options:

- **Mandatory Option:** The supplier must obligatorily include an offer with the option, otherwise the offer will be considered irregular. CEA reserves the right to decide whether to exercise this option or not, but the price of the option must be clearly stated in the offer.
- **Non mandatory type Option:** The supplier has the choice to propose or not propose the option. If the option is not proposed, the supplier will not necessarily be disqualified. CEA reserves the right to decide whether to exercise the option or not.