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F +31 88 866 06 30**System/Subsystem Requirements Specification****SEM | 0.1.0.0****SEM Element Requirements**

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1 Introduction

2 1.1 Identification

3 This document contains information and requirements pertaining to the Scanning Electron Microscope
4 (SEM) that will be purchased by TNO. This SEM will be added to the tool set for experimental and
5 scientific work that the Nano-instrumentation group does in the field of Semiconductor and Quantum
6 research. The SEM will be installed in the “Van Leeuwenhoek Laboratory” (VLL) in Delft.

7 1.2 System overview

8 Scanning electron microscopy is a mature technology, therefore TNO expects that a commercial off
9 the shelf (COTS) SEM will fulfil the scientific needs of TNO. This expectation is taken into account
10 when writing this requirements document. This requirements document is focussing more on the
11 samples and measurement area that can be loaded into, or measured in the SEM, than on the
12 imaging and detector side of the SEM. The second focus is set on the software of the SEM.

13 Intended method of use

14 The main intended use of the SEM is to investigate a sample surface before and after an experiment,
15 to observe any changes to the surface. Changes in surface which can be expected, among others,
16 are:

- 17 • Increase of very fine surface roughness.
- 18 • Blistering or delamination of one or more material layers.
- 19 • Changes in oxidation state of surface material.
- 20 • Increase of contamination on the sample surface.
- 21 • Increase in amount of particles.
- 22 • Changes in size and shape of particles which have been exposed.

23
24 Investigation of presence of materials in coatings and particles is also anticipated, which is done using
25 EDX.

26
27 Measuring of features on samples or measuring distances between features with high accuracy will
28 regularly be done. Furthermore, accurately measuring sample sizes of samples up to at least 10 cm in
29 X or Y directions is done regularly.

30 SEM analysis procedure

31 When we receive a sample from a customer, an initial visual inspection is performed. After this, an
32 analysis is done with LM. Using the LM, we can assess areas of interest which can then in a
33 subsequent step be analysed in more detail using SEM and/or EDX.

34
35 Once we obtain the information on which positions on the sample the SEM analysis needs to be
36 performed, the sample will be transported to the SEM and mounted on a sample mount, supplied by
37 the SEM manufacturer. Mounting the sample to the mount can be done by mechanical force of
38 clamping from the side or on the top of the sample, or by using adhesives like carbon stubs. This is
39 very dependent on the sample, since some samples have strict requirements. For example, some
40 samples may not be mounted using any adhesive due to contamination requirements, and some
41 samples may not be clamped from the top (coating) due to risk of damaging sensitive parts of the
42 sample.

43

The sample will be loaded by opening the SEM main vacuum chamber and mounting it on the proper mount on the mechanical stage interface. When this is done, a navigation camera (navcam) image is made, after which the chamber is closed and pumped down. It is also possible to make a navcam image in the system when it is pumped down. Furthermore, it should be possible to use a sample picture made with any camera to be loaded in the SEM software as navcam image.

After the system is pumped down to high vacuum, the SEM electron beam is enabled and a course beam alignment (focus, astigmatism, wobble) is done either on the edge of the sample, or on the surface of the sample mount. Following this, an alignment between SEM image and navcam location is done, to assure that the position on the navcam image is accurate.

Next step is, if required for the analysis, to define a custom coordinate system. This can be done by moving to certain features on a sample (markers, edges, or other clearly defined locations), and defining which custom coordinates these locations obtain. This is usually done when a SEM analysis is done before and after an experiment at TNO. The custom coordinate system makes sure we find back locations before and after the experiment on the sample within a few um accuracy and repeatability. Furthermore, sometimes we need to mimic the coordinate system of another experimental setup with high accuracy.

When the coordinate system setup is done, the optimum imaging settings must be found by tuning several parameters, such as electron source acceleration voltage, beam current, working distance, choice of detector, with- or without form of charge mitigation.

When the optimum settings are found, sample analysis is done on several locations on the sample. Often a set of pre-defined magnifications are used to make images at each location, varying from very low magnification with high horizontal field width (HFW) to high magnification. If possible, this can be automatized. When required, a raster of images is made to obtain high magnification SEM images over a larger surface area. Automatizing this will reduce the amount of work for the SEM operator and reduce the chance of making human errors in the process.

Regularly EDX analysis needs to be performed. The EDX detector (EDS) should be able to be used both on non-charging and charging samples. Therefore, the EDS should be able to work under low vacuum conditions. The EDX software should be capable of selecting areas to perform analysis and making an EDX element map for a large area, in which elements can be visually identified by means of colour overlay on the SEM image.

For some SEM analysis jobs, it is required that both SE and BSE images are made on all locations where imaging needs to be done. It is therefore required that both an SE and BSE image can be acquired at the same time. This will reduce overhead of performing two image acquisitions sequentially, and both images are obtained from the sample at the exact same time and under the same conditions.

Each image which is acquired is saved as a high-resolution image, such as 16-bit TIFF file. In the filename parameters such as date, sample name, coordinates, detector name and magnification are included. This can be done by the SEM operator. However, it is preferential that the GUI software can include these parameters in the filename automatically, to significantly reduce SEM operator time and reduce the chance of making a human error.

As part of some SEM analysis jobs, it can be useful to perform direct image analysis on some images. This can be the (preferentially automatic) measuring of the number of particles in an image and obtaining a list of particles with particle dimensions, ellipticity, surface area, average size distribution, etc.

Since most samples of customers of TNO are sensitive to carbon deposition, the SEM system should minimize the amount of carbon deposition on samples. Therefore, it is required that the SEM vacuum chamber is very clean, and can be cleaned (e.g. by means of plasma cleaner) when this is required.

1.3 Document overview

The purpose of this document is to state and clarify the requirements TNO has for a new SEM.

The last column of each requirement contains the verification method (VM), this could be; (T)est, (R)evue, (D)emonstration, (A)nalysis, (I)nspect, or (C)ertification. The full detail definitions are described in chapter 3.1.

Remarks noted within a requirement must be seen as guidelines for addressing that requirement. They also provide additional information of relevance and clarify the relationship with other requirements.

This document uses the definitions as explained in chapter 3.

The SEM shall be capable of fulfilling all requirements simultaneously, unless indicated otherwise in the requirement.

All preferences that are stated as compliant in the supplier's tender document, automatically become requirements (demands) upon awarding the tender. This requirement document will be updated to represent this.

Stated performance values for such preferences in the supplier's tender document shall, if agreed on by TNO, become the stated required values, whether they are better or worse than the wished value.

1.4 Relationship to other documents

Not applicable, this is a standalone document.

2 1 Applicable and reference documents

2 This section lists the applicable documents (section 2.1), and the reference documents (section 2.2).
3 An applicable document is a binding requirement when the supplier states to be compliant. A
4 reference document is a document that explains or clarifies a requirement.

5 2.1 Applicable documents

6 Appendix D001, imaging quality of SEM
7 Appendix D002, minimum required detectors
8 Appendix D003, used samples and analysis area
9 Appendix D004, used samples and analysis area desired
10 Appendix D005, EDX performance
11 Appendix D006, contamination experiment
12 Appendix D007, forbidden material list
13 Appendix D008, Custom coordination method desire
14
15 ISO 3834-2 (quality requirements for fusion welding of metallic materials – part 2: Comprehensive
16 quality requirements.
17 Directive 2006/42/EC; Machine Directive.
18 Machine (Commodities act) Decree; Decree of 30 June 1992 regarding rules related to machine
19 safety.
20 NEN 3140; Additional Dutch provisions for low-voltage installation.
21 NEN 3840; High-voltage installation and word responsible party.
22 NEN-EN 50110 Operation of electrical installations.
23 NEN-EN 60204-1 Electrical equipment of industrial machines, general requirements.
24 NEN-EN-ISO 12100.
25 EMC 2004-108-EG.
26 Working conditions act of 1998; Working Conditions Act 22.
27 Working conditions decree of 1997; Working conditions Decree.
28

29 2.2 Reference documents

30

3 1 Definitions, abbreviations and acronyms

2 3.1 Definitions

May	Expresses permissive guidance.
Shall	Expresses a characteristic which is to be present in the item which is the subject of the specification, i.e. "shall" expresses a binding requirement.
Should	Expresses a target or goal to be pursued, but not necessarily achieved.
Will	Expresses a declaration of intent on the part of a party, usually the sponsoring or acquiring organisation. "Will" does not express a binding requirement. "Will" may also be used in cases where the simple future tense is required, for example, "The operating system will be supplied by the government.". Will may also express simple futurity. Any statement which employs the term "will", if used in chapter 4, should be present as a note so as to be clearly distinguishable from requirements.
Goal	The desired value for a requirement.
Threshold	The acceptable value for a requirement.
Remark	Information that is meant to clarify or supplement a requirement.
Rationale	Reasons or logical basis for a requirement.
Accuracy	The degree to which the result of a measurement, calculation, or specification conforms to the correct value or a standard.
Reproducibility	The degree of agreement between measurements or observations conducted on replicate specimens in different locations by different people, as part of the precision of a test method.
Sample	Object to be measured.
State	A required, permitted or prohibited condition of the system.
Mode	A group of functions related to an aspect of use.
Test (T)	The operation of the system, or part of the system, using instrumentation or other special test equipment to collect data for later evaluation.
Demonstration (D)	The operation of the system, or a part of the system that relies on observable function not requiring the use of the instrumentation, special test equipment, or subsequent analysis.
Analysis (A)	The processing of accumulated data obtained from other qualification methods. Examples are reduction, interpolation, or extrapolation of test results.
Inspection (I)	The visual examination of system components, documentation, etc.
Certification (C)	A declaration by designated stakeholder, usually the supplier or developer.
Review (R)	Detailed review of the received specification of the supplier or developer on the (sub-)system.

Abbreviations and acronyms

In the Table 1 the abbreviations and acronyms are listed, some are not applicable for the SEM

Table 1 abbreviations and acronyms

Abbreviation	means
4N	4-nines
AISI	American Iron and Steel Institute
AMU	Atomic mass unit
BSE	Backscatter electron
CDA	Compressed Dry Air
CDR	Critical Design Review
CE	European Conformity
CF	Conflat
COTS	Commercial off-the-shelf
CR	Clean Room
EDX	Energy dispersive X-ray (spectroscopy)
EMC	Electromagnetic compatibility
EMO	Emergency off
EtherCAT	Ethernet for Control Automation Technology
EUV	Extreme ultraviolet
EUVL	Extreme ultraviolet lithography
Exif	Exchangeable image file format
FAT	Factory acceptance test
FMEA	Failure mode and effects analysis
FWHM	Full width at half maximum
GN2	Gaseous nitrogen
GUI	Graphical user interface
HFW	Horizontal field width
HMI	Human machine interface
HWCI	Hardware configuration item
HW	Hardware
ICD	Interface control document
IF	Interfase
IRS	Interface requirements specification
ISO	International Organization for Standardization
MLM	Multilayer mirrors
MMA	Methyl methacrylate

Abbreviation	means
OI	Open Item
PC	Personal computer
PCW	Process cooling water
PDF	Portable Document Format
PDR	Preliminary Design Review
PLC	Programmable logic controller
ppm	Parts per million
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
RDP	Remote Desktop Protocol
RGA	Residual gas analyzer
SA	Surface analysis
SAT	Site acceptance test
SE	Secondary electron
SEMI	Semiconductor Equipment and Materials International
SNR	Signal-to-noise ratio
SoW	Statement of Work
STEP	Standard for the Exchange of Product model data (ISO 10303)
SyRS	System requirements specification
SW	Software
RDC	Radial Distribution Chamber
TBD	To be determined
TBC	To be confirmed
TMP	Turbomolecular pump
TNO	Netherlands Organisation for Applied Scientific Research
UHV	Ultra-high vacuum
UPS	Ultraviolet photoelectron spectroscopy
UPS	Uninterruptible power supply
UV	Ultraviolet
VLL	Van Leeuwenhoek Labatorium (clean room)
VM	Verification method
XCDA	eXtreme Clean Dry Air
XPS	X-ray photoelectron spectrometer
XYZ	Right handed cartesian coordinate system

4 Requirements

4.1 Identification of external interfaces

The SEM could have the following external interfaces. 'TBD' in most cases means that it depends on the design of the SEM, and the final location of the SEM in the VLL. TNO expects that in most cases this can be achieved without any problems. The installation requirement from the supplier will clarify the requirement from the supplier. The final interfaces will be agreed on during the CDR meeting in the ICD.

Table 2: SEM interfaces.

interface type	identification	location
<i>Mechanical</i>		
SEM to Floor	SEM to Floor	Laboratory or clean room
<i>Supplies</i>		
Power	Power	Laboratory or clean room
Process cooling water	PCW	TBD
Compressed dry air	CDA	Laboratory or clean room
Nitrogen	N ₂	Laboratory or clean room
<i>Signals</i>		
Interlocks	Interlocks	TBD
remote access	remote access	TBD
<i>Environment</i>		
Laboratory or clean room	VLL	-

4.2 Configurations

The SEM might have two configurations, one during testing in the factory, using common ancillary equipment that will not be part of the delivery, and a configuration installed at TNO. The supplier is responsible for both configurations, if applicable.

4.3 System function and performance requirements

SEM generic requirements

R-0000-005 : Meet all requirements

Description	VM
The SEM supplier shall deliver a system that is capable of meeting all the stated requirements, and accepted preferences, in this document at the same time, unless indicated otherwise in a specific requirement.	R

Rationale	Required to meet main function of the SEM system.
-----------	---

R-0000-010 : Human, machine and sample safety

Description	VM
The SEM shall ensure, human, machine and sample safety. Remark: close-out of this requirement is done by review of the provided FMEA and demonstration that the implemented mitigation actions function, therefor VM is demonstration.	D
Rationale	TNO requires a safe system

R-0000-015: Operation lifetime

Description	VM
The SEM system shall have an operation lifetime of at least 10 years. Remark: Close out shall be done through review of design, proof of heritage, used materials and equipment.	R
Rationale	Minimum expected lifetime of such a system.

SEM imaging

TNO considers the imaging part of the SEM the core business of the SEM supplies, also looking at the stated performance of the SEM's on the imaging part, the differences are very limited. Because of this, TNO will have in this chapter more high level requirements compared to some other chapters of this requirements document.

R-1000-005 : Source for imaging and material analysis

Description	VM
The SEM shall have a source that matches best the stated requirements on both imaging (R-1000-025) and material analysis (R-2000-005).	R
Rationale	The SEM will be used for both imaging and material analysis. A source that would perform very well on one of those two items, but very poor on the other is not desired with the foreseen use of the SEM.

R-1000-010 : Electron optical column

Description	VM
The Electron optical column shall enable the SEM to meet the required imaging (R-1000-025) and material analysis (R-2000-005) requirement stated in this document.	R

Rationale	TNO seeks a SEM that can be used for both imaging and material analysis using EDX, the SEM Electron optical column shall ensure that both required functions are possible.
-----------	--

1

2 R-1000-015 : Source lifetime demand

Description	VM
The SEM source shall have a minimum lifetime of 2 years when operated 1000 hours per year. Remark 1: close out of requirement by proof from similar systems in use, or free repair when the source fails before stated requirement. Remark 2: lifetime is stated a time before full replacement of source, not tip maintenance or exchange. The supplier shall state the expected time before tip maintenance or tip exchange is needed	R
Rationale	The use-case of the SEM is not high volume SEM use, therefore the stated use per year is on the higher side of use. However, TNO desires low maintenance time and cost.

3

4 R-1000-020 : Source lifetime desire

Description	VM
The SEM should have a minimum lifetime of 10 years when operated 1000 hours per year. Remark 1: close out of requirement by proof from similar systems and use, or free repair when the source fails before stated requirement. Remark 2: the supplier shall state in the tender document the promised lifetime. Remark 3: lifetime is stated a time before full replacement of source, not tip maintenance or exchange. The supplier shall state the expected time before tip maintenance or tip exchange is needed.	R
Rationale	The use-case of the SEM is not high volume SEM use, therefore the stated use per year is on the higher side of use. However, TNO desires low maintenance time and cost.

5

6 R-1000-025 : Imaging quality demand

Description	VM
The SEM shall meet the stated requirements on imaging as stated in appendix D001. Remark: this consists for example, but not limited to: - resolution, - brightness, - tuneability of parameters like voltage, current	A
Rationale	TNO seeks a general use SEM, and is of the opinion that the stated values are represented in this requirement

7

1 **R-1000-035 : Imaging detectors**

Description		VM
TNO concluded that both, different names and, slightly different implementations are used for similar detectors. To ensure equal opportunities for every supplier, the SEM shall be equipped with the detectors needed to generate the required measurements as stated in appendix D001, and the minimum required detectors stated in appendix D002. Remark 1: In the tender document the used/ offered detectors shall be stated, and the detectors that are not offered. Remark 2: VM is stated as analysis, this because the detectors will be tested, and the results analysed on the stated performance/ function. First check will be review of the offered detectors.		A
Rationale	Imaging is the core requirement of the SEM, the detectors are the needed for this. The presented requirement measurements in appendix D001, and the support appendix D002 should ensure that TNO has a SEM that fulfils our use-case.	

2

3 **R-1000-040 : Charging samples**

Description		VM
The SEM shall have one or more mitigations in place to measure a sample as described in appendix D003. Remark 1: Several mitigation options are present in the market, TNO does not have a specific preference for the proposed solution, and several mitigation solutions may be used for the specific best solutions for the sample, or the measurement type Remark 2: close-out of this requirement is verification that stated samples can be measured according to requirement R-1000-025.		D
Rationale	TNO must be able to measure charging samples, therefore mitigation against charging samples are needed	

4

5 **R-1000-045 : Beam acceleration voltage on sample between 0.1 keV and 30 keV**

Description		VM
The beam energy on the sample shall be able to be controlled between 0.1 keV and 30 keV.		D
Rationale	Lower energy on the sample from the beam will enable the imaging of the top surface of the sample	

6

7 **R-1000-050 : Beam acceleration voltage on sample between 0.1 keV and 30 keV**
8 **stepless desire**

Description		VM
The beam energy on the sample should be able to be controlled stepless, with a resolution of not bigger than 50 V steps, between 0.1 keV and 30 keV.		D

Remark: the supplier shall state the minimum step size in the tender document	
Rationale	Lower energy on the sample from the beam will enable the imaging of the top surface of the sample

1

2 R-1000-055 : Horizontal field width at eucentric height

Description		VM
The SEM shall have a maximum horizontal field width (HFW), at eucentric height, of at least 2 mm, both for SE and BSE imaging.		A
Rationale	The stated horizontal field width will provide a nice balance between imaging resolution and ease and speed of finding location of interest.	

3

4 R-1000-056 : Horizontal field width at low vacuum, at eucentric height desire

Description		VM
The SEM should ideally have a large maximum HFW of 2 mm or more when imaging non-conducting samples, at eucentric height.		A
Rationale	When imaging non-conducting samples, sometimes a detector aperture or cone aperture is used, limiting the maximum HFW. A larger maximum HFW provides more flexibility.	

5

6 R-1000-057 : Beam current setting

Description		VM
The SEM shall have the possibility of tuning the beam current stepless.		R
Rationale	The beam current is an essential parameter to tune to obtain the best imaging settings.	

7

8 R-1000-060 : Imaging multiple channels simultaneously demand

Description		VM
It is expected that the SEM has several detectors, the SEM shall be able to image at least 2 detectors simultaneously.		D
Remark: imaging simultaneously is not equal to showing all the images simultaneously, TNO accepts that not all images will be displayed at the same time.		
Rationale	Different detectors show different images. It is very useful if images are taken simultaneously. It would be nice if those could be displayed next to each other, but TNO understands that at a certain time the screens are a limiting factor.	

9

10 R-1000-065 : Imaging multiple channels simultaneously desire

Description		VM
-------------	--	----

It is expected that the SEM has several detectors, the SEM should be able to image all detectors simultaneously.		D
Remark 1: the supplier shall state (if not all detectors can be imaged simultaneously) the detectors that can be imaged simultaneously		
Remark 2: imaging simultaneously is not equal to showing all the images simultaneously, TNO accepts that not all images will be displayed at the same time.		
Rationale	Different detectors show different images. It is very useful if images are taken simultaneously. It would be nice if those could be displayed next to each other, but TNO understands that at a certain time the screens are a limiting factor.	

1

2 R-1000-070 : Segmented detector

Description		VM
The SEM shall be equipped with at least one segmented detector, which can be read out per segment to be able to obtain detailed topographical information.		R
Remark: in the tender document the supplier shall state the amount of segments.		
Rationale	Making images with certain segments can show shadow effects and give information about height/depth.	

3

4 R-1000-075 : Use of all detectors without manual hardware changes desire

Description		VM
The SEM should be able to use all offered detectors without any manual hardware actions needed.		D
Remark: If not possible for all the detectors, the supplier shall state what is possible.		
Rationale	TNO seeks a complete SEM, manual removing, or installing detectors is not desired, this because it will limit for instance automated measurements with different detectors.	

5

6 R-1000-080 : Electron energy filtering option desire

Description		VM
The SEM should be equipped with a BSE detector where the detected electron energy can be filtered.		R
Rationale	Filtering out BSE electrons with certain energy before arriving in a detector can give extra information on material properties.	

7

8 R-1000-081 : Stage bias desire

Description		VM
-------------	--	----

The SEM should be equipped with stage bias with a tuneable range between at least -250 V to +250 V.		D
Remark: the performance of the stage bias will be stated in the tender document, if applicable		
Rationale	A stage voltage bias can improve imaging resolution and quality in certain demanding situations. Furthermore it could be used for charge filtering.	

1
2

3 R-1000-085 : Imaging integration settings

Description		VM
In the SEM software it shall be possible to set or tune, at least the following imaging settings: • Pixel-, line-, frame-integration options. • Drift correction option. • Dwell time setting. Remark: It is expected that this can all be done from within the SEM software GUI.		R
Rationale	These imaging settings are necessary to prevent certain charging effects and obtain the best images. Drift correction is required to be able to image when there is some sample or image drift.	

4

5 Material analysis

6 To TNO's knowledge all suppliers are able to deliver the SEM with the COTS Energy Dispersive X-
7 rays Spectroscopy EDX, i.e. Bruker or Oxford instruments, or have designed a company EDX. To not
8 limit any suppliers proposal, TNO will not require a specific supplier, but will require the stated
9 performance requirements in this chapter.

10

11 R-2000-005 : Material analysis (EDX)

Description		VM
The SEM shall be delivered with an integrated, and functional EDX, with the requirements stated within appendix D005. Remark 1: TNO opted to state the requirements in one appendix document, this because TNO is of the opinion that all suppliers can deliver an EDX to the stated requirement, this by either installing a COTS EDX, or install an in-house developed EDX. Remark 2: the supplier shall state in the tender document the selected detector, with all the specifications.		D
Rationale	TNO requires to measure the composition of the sample, this is commonly done with SEM EDX.	

12

13 R-2000-010 : Material analysis samples

Description	VM
-------------	----

The EDX of the SEM shall be able to measure the stated samples in appendix D003		D
Remark: including in this sample list, <u>charging samples</u> are present. It is expected that charge mitigation will be required. This may be done by so called low vacuum SEM.		
Rationale	In appendix D003 the common used samples are stated, the EDX and SEM must be able to measure these samples.	

1

2 R-2000-015 : Minimum detector surface EDX

Description		VM
The minimum detector surface area shall be 60 mm ² .		I
Rationale	Requirement to ensure similarity in offers, bigger detector surfaces may be offered, or presented as an option.	

3

4 R-2000-020 : Level of integration desire

Description		VM
The by the supplier selected EDX should have an as high as possible integration of the EDX control into the SEM control system.		D
Remark 1: The supplier shall provide documentation (up to 10 slides) how the level of integration of the EDX is achieved in the overall SEM control system.		
Remark 2: the stated level of integration will be validated with demonstration.		
Rationale	The higher the level of integration, the easier it will become for the operator, increasing the efficiencies of operation of the SEM	

5

6 Sample's and sample measurement area to be measured

7 This chapter will host the requirements related to the nominal samples that need to be able to be
8 measured with the SEM. TNO expects that the demands are possible within a COTS SEM, and is
9 hopeful that with smart sample holders, most of the desired samples also can be loaded, and
10 measured.
11

12 R-3000-005 : Sample size loading demand

Description		VM
The SEM shall be able to load the samples that are stated in appendix D003		D
Rationale	Commonly used samples within the domain that TNO works in, will be used.	

13

14 R-3000-010 : Sample size loading desire

Description		VM
-------------	--	----

The SEM should be able to load samples which are larger than stated in appendix D003, which is explained in appendix D004.		D
Rationale	Being able to load samples which are larger than the baseline samples in D003 will increase the use-case for the SEM.	

1

2 R-3000-015 : Sample measurement area demand

Description		VM
The SEM shall be able to measure the samples in the stated measurement area in appendix D003 without making use of stage rotations.		D
Remark: it is expected that an XYZ translation of the sample stage will be used to position the sample to measure at the required measurement spot.		
Rationale	The SEM will be used to scan across the loaded sample, therefore the SEM must be able to translate the sample to the desired position	

3

4 R-3000-020 : Sample measurement area desire

Description		VM
The SEM should be able to measure a surface area which is larger than stated in appendix D003 baseline. This is explained in appendix D004. Remark 1: it is expected that an XYZ translation of the sample stage will be used to position the sample to measure at the desired measurement spot. It is allowed to also use a rotation to increase the measurement area. If this rotation is used, this shall be fully automated in the software of the SEM. Remark 2: if rotation is used, this shall be stated in the tender documentation.		D
Rationale	The SEM will be used to scan across the loaded sample, therefore the SEM must be able to translate the sample to the desired position. An increase in measurable area will increase the use-case of the SEM.	

5

6 R-3000-030 : Sample measurement at tilt demand

Description		VM
The SEM shall be able to tilt, and measure, the specified samples, in the specified measurement area, and to the specified angle as stated in appendix D003.		D
Remark: The supplier shall indicate how the design of the sample stage will prevent the samples from movement during tilting.		
Rationale	Measuring under a tilt angle will provide additional information from the sample surface.	

7

1 **R-3000-035 : Sample measurement at tilt desired**

Description		VM
The SEM should be able to tilt more than 60 degrees, as stated in appendix D003.		D
Remark: The supplier shall indicate how the design of the sample stage will prevent the samples from movement during tilting		
Rationale	Measuring under a tilt angle will provide additional information from the sample surface.	

2

3 **R-3000-045 : Sample weight demand**

Description		VM
The SEM shall be perform all stated SEM requirements with a sample weight up to 0,5 kg, with the exemption of the tilt motion.		T
Remark: this stated sample weight is excluding sample holders weight that are required for normal SEM usage, with the stated samples in appendix D003, and if applicable appendix D004, and therefor are in the delivery of the SEM.		
Rationale	Stated sample weight is the maximum sample weight that TNO expects.	

4

5 **R-3000-050 : Sample weight desired**

Description		VM
The SEM should be perform all stated SEM requirements with a sample weight up to 2,5 kg, with the exemption of the tilt motion. Remark 1: this stated sample weight is excluding sample holders weight that are required for normal SEM usage, with the stated sample in D003, and if applicable D004, and therefor are in the delivery of the SEM. Remark 2: the supplier shall state the maximum sample weight		T
Rationale	Stated sample weight is the maximum sample weight that TNO expects with some additional margin.	

6

7 **R-3000-055 : Sample weight including tilt motion demand**

Description		VM
The SEM shall be perform all stated SEM requirements with a sample weight up to 0,5 kg, including the tilt motion. Remark: this stated sample weight is excluding sample holders weight that are required for normal SEM usage, with the stated sample in D003, and if applicable D004, and therefor are in the delivery of the SEM.		T
Rationale	Stated sample weight is the maximum sample weight that TNO expects.	

8

1 **R-3000-060 : Sample weight including tilt motion desired**

Description		VM
The SEM should be perform all stated SEM requirements with a sample weight up to 2,5 kg, including the tilt motion. Remark: this stated sample weight is excluding sample holders weight that are required for normal SEM usage, with the stated sample in D003, and if applicable D004, and therefor are in the delivery of the SEM.		T
Rationale	Stated sample weight is the maximum sample weight that TNO expects with some additional margin.	

2

3 **R-3000-065 : Mounting of stated samples**

Description		VM
The SEM shall enable mounting of samples as stated in D003, and if applicable for the samples stated in D004. Remark: The supplier shall state in the tender documents how the supplier intends to mount the samples.		D
Rationale	The stated samples are the normally used samples for TNO, an option is to have sample holders that are dedicated for the stated sample holders, see option R-0000-145, another option is that the SEM is equipped with a sample holder that can easily mount all the stated samples	

4

5 **R-3000-066 : Limit of use of carbon tape desire**

Description		VM
The use of carbon tape for mounting the defined standard samples, see appendix D003 and D004, should be kept as minimal as possible.		R
Rationale	Carbon tape will contaminate samples, sample holders, and the SEM. For the stated normally used samples it is considered beneficial of mounting of those samples can be done in dedicated sample holders that do not require carbon tape, see R-0000-145	

6

7 **R-3000-070 : Mounting of sample time needed demand**

Description		VM
The SEM shall enable the mounting of the sample on the sample stage within 10 minutes for all the samples indicated in appendix D003 and if applicable D004 Remark: this is the time without pump down of the system.		T
Rationale	Sample holders that enable easy mounting of the sample will reduce the time required for mounting the samples, and will reduce the risk of sample damage and will save time during loading	

1

2 **R-3000-075 : Mounting of sample time needed desired**

Description		VM
The SEM should enable the mounting of the sample on the sample stage within 2 minutes for all the samples indicated in appendix D003 and if applicable D004. Remark: this is the time without pump down of the system.		T
Rationale	Sample holders that enable easy mounting of the sample will reduce the time required for mounting the samples, and will reduce the risk of sample damage and will save time during loading	

3

4 **R-3000-076 : Mounting interface**

Description		VM
The SEM supplier shall share the interface description to the sample stage in the tender document. Remark: detailed 2D and STEP files are expected to be part of this delivery.		R
Rationale	Having the interface description will enable TNO to judge the complexity of the interface and enable TNO to design sample holders that can interface with the sample stage	

5

6 **R-3000-080 : Mounting of non-stated samples**

Description		VM
The SEM shall ensure that non-stated samples can be mounted safely. Remark 1: This may be achieved by ensuring a (large) flat surface that enables the sample to be secured with carbon tape. Remark 2: The supplier shall state in the tender documents how the supplier intends to mount non-stated samples. Remark 3: it is expected that this mounting can be done within 10 minutes, if this is not expected the supplier shall put forward this in the tender document		R
Rationale	As stated, this is for the nonstandard samples, that are not used that often to grant dedicated sample holders, however TNO still needs to be able to mount these samples safely.	

7

8 **R-3000-085 : Sample stage rotation**

Description		VM
The SEM shall be able to rotate the stated samples in appendix D003 with a range of +/- 180°		D
Rationale	Rotation of the samples are required for alignment of samples to, in example detectors.	

1

2 **R-3000-086 : Compucentric sample stage rotation**

Description		VM
The SEM shall be able to perform compucentric rotations of the stage, when requested by the operator.		D
Rationale	A compucentric stage is capable of preserving the region of interest focused and in the field of view after performing a rotation. This feature will be used regularly.	

3

4 **R-3000-090 : Sample position repeatability demand**

Description		VM
With the stated sample motions of requirement R-3000-015, and the stated sample weight in requirement R-3000-045, the repeatability of the sample stage position shall be better than or equal to 3 um. Remark 1: this requirement directed to the demanded measurement areas and sample weight. Unless indicated differently TNO expects that when a demanded requirement are upgraded to a desired requirement, the stated value of this requirement still applies. If this is not the case, the supplier shall make this clear in the tender document. Remark 2: repeatability is defined as; how well does the sample stage does return back to previous position. Remark 3: this requirement is without unloading the sample Remark 4: this requirement is without tilt of the sample		T
Rationale	Good repeatability will decrease the time for the operator to find back a location of interest.	

5

6 **R-3000-095 : Sample position repeatability desired**

Description		VM
With the stated sample motions of requirement R-3000-015, and the stated sample weight in requirement R-3000-045, the repeatability of the sample stage position should be better than or equal to 1 um. Remark 1: this requirement direct to the demanded measurement areas and sample weight. Unless indicated differently TNO expects that when a demanded requirement is upgraded to a desired requirement, the stated value of this requirement still applies. If this is not the case, the supplier shall make this clear in the tender document. Remark 2: repeatability is defined as; how well does the sample stage does return back to previous position. Remark 3: this requirement is without unloading the sample Remark 4: this requirement is without tilt of the sample		T
Rationale	Good repeatability will decrease the time for the operator to find back a location of interest.	

7

1 R-3000-100 : Stage position accuracy demand

Description		VM
With the stated sample motions of requirement R-3000-015, and the stated sample weight in requirement R-3000-045. The accuracy of the sample stage shall be better than or equal to 3 um over a travel range of 100 mm in either X or Y direction. Remark 1: this requirement direct to the demanded measurement areas and sample weight. Unless indicated differently TNO expects that when a demanded requirement is upgraded to a desired requirement, the stated value of this requirement still applies. If this is not the case, the supplier shall make this clear in the tender document. Remark 2: accuracy is defined as; how well does the sample stage know it absolute position. Remark 3: this requirement is without unloading the sample Remark 4: this requirement is without tilt of the sample		T
Rationale	For certain measurements or experiments it is important to know coordinates of certain features or particles, or to measure the dimensions of features with high accuracy.	

2

3 R-3000-105 : Stage position accuracy desire

Description		VM
With the stated sample motions of requirement R-3000-015, and the stated sample weight in requirement R-3000-045. The accuracy of the sample stage should be better than or equal to 1 um over a travel range of 100 mm in either X or Y direction. Remark 1: this requirement direct to the demanded measurement areas and sample weight. Unless indicated differently TNO expects that when a demanded requirement is upgraded to a desired requirement, the stated value of this requirement still applies. If this is not the case, the supplier shall make this clear in the tender document. Remark 2: accuracy is defined as; how well does the sample stage know its absolute position. Remark 3: this requirement is without unloading the sample Remark 4: this requirement is without tilt of the sample		T
Rationale	For certain measurements or experiments it is important to know coordinates of certain features or particles, or to measure the dimensions of features with high accuracy.	

4

5 R-3000-110 : Resolution of stage movements

Description		VM
The control of the stage shall have the following resolution: - XYZ= 0.0001 mm - R = 0.1° - Tilt =0.5° Remark: We expect that both can use absolute coordinates and relative steps can used to move the stage via the GUI.		D
Rationale	Common and fitting resolution for such a sample stage.	

R-3000-115: Analysis position readout

Description		VM
The SEM shall display a readout of all axes of the analysis position (i.e. at least x, y, z, R and θ) in the SEM software.		D
Rationale	The readout of the analysis position is necessary to confirm the position of the analysis position and for reporting the position to customers.	

Vacuum system and vacuum quality

The vacuum quality of a SEM must be up to the level that it does not disturb the measurement of the SEM. TNO does not expect that during a SEM measurement no carbon growth on the sample will accrue. This growth is also depended on the cleanliness of the sample. The set requirement is to ensure that the SEM is clean enough to be used for TNO's use cases.

R-4000-005 : Contamination growth demand

Description		VM
The SEM shall meet the stated values, with the stated method in appendix D006 with respect to contamination growth. Remark: if the stated method is not possible perform, this shall be stated during the question period of the tender phase, with a counter proposal how to obtain the values TNO seeks, TNO will investigate to proposal.		A
Rationale	Contamination growth on samples is a problem, potentially not only for the measurement but also for the follow up experiment.	

R-4000-010 : Contamination growth desired

Description		VM
The SEM should meet the stated values, with the stated method in appendix D006 with respect to contamination growth.		A
Rationale	Contamination growth on samples is a problem, potentially not only for the measurement but also for the follow up experiment.	

R-4000-015 : Cleaning of SEM with plasma cleaner

Description		VM
The SEM shall have a plasma cleaner installed that is able to clean the measurement chamber. Remark 1: Because TNO expects that this a common component on a SEM, TNO expect that either COTS plasma cleaner will be offered, or an "inhouse" developed cleaner.		D

Remark 2: Because of the expected common component, no specific performance requirements are set. TNO however expects, <u>in example</u>, an Evactron model 25 or 50, or a plasma cleaner similar performance. Remark 3: this plasma cleaner does not necessary be directly connected to the measurement chamber of the SEM Remark 4: Ideally the plasma cleaner is permanently installed on the SEM Remark 5: the tender document will state the selected plasma cleaner, the location, and used method of plasma cleaning	
Rationale	TNO expects that the SEM is clean, and does because of that influences the SEM measurement or sample, see requirement R-4000-005. However it could happen that the SEM is contaminated. Without a plasma cleaner it would be very difficulted to clean the chamber. TNO does not expect to use the plasma cleaner on sample.

1

2 R-4000-025 : Forbidden material list

Description		VM
The SEM shall not use the stated materials in appendix D007. Remark: if a material is listed in appendix D007 that is needed for functional or performance, this shall be ideally stated in the tender document, but at latest in the CDR documentation. TNO expects that mitigation options are present to resolve the used material conflict.		R
Rationale	The SEM might be used before a sample will be subjected to harsh experimental conditions. In those harsh experimental conditions it vacuum conditions, and the materials present in the SEM could affect the experimental outcome of the experiment.	

3

4 R-4000-030 : Materials in contact with sample desire

Description		VM
Unless needed for SEM performance the material(s) that are in contact with the sample should be aluminium. Remark: If there are items in contact with the sample that are made from a different material, the supplier shall state this in the tender document.		R
Rationale	The samples may be used in setups with very stringent material requirements, cross contamination from the SEM could serious impact these experiments and setups. The mitigation this risk TNO has the string rules to which materials the samples come in contact with.	

5

6 R-4000-035 : Pump down time with sample demand

Description		VM
The SEM shall reach the required high vacuum level for SEM operation within 10 minutes after loading a sample as stated in appendix D003 and D004 from atmosphere with a sample that has been exposed to atmospheric conditions for at least 24 hours.		T

Rationale	The use-case of the SEM is not high volume SEM use, therefor reasonable loading time is acceptable for TNO
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1

2 **R-4000-040 : Pump down time with sample desired**

Description	VM
The SEM should reach the required high vacuum level for SEM operation within 2 minutes after loading a sample as stated in appendix D003 from atmosphere with a sample that has been exposed to atmospheric conditions for at least 24 hours.	T
Rationale	The use-case of the SEM is not high volume SEM use, therefor reasonable loading time is acceptable for TNO, however reduced waiting time after loading will increase effective of the operation of the SEM

3

4 **R-4000-045 : Venting time demand**

Description	VM
The venting time, including all internal SEM actions that are required, shall be within 10 minutes after giving the venting signal. Remark: Internal SEM actions could be stop and cool down of SEM source.	T
Rationale	The use-case of the SEM is not high volume SEM use, therefor reasonable loading time is acceptable for TNO.

5

6 **R-4000-050 : Venting time desired**

Description	VM
The venting time, including all internal SEM actions that are required, should be within 2 minutes after giving the venting signal. Remark: Internal SEM actions could be stop and cool down of SEM source.	T
Rationale	The use-case of the SEM is not high volume SEM use, therefor reasonable loading time is acceptable for TNO, however reduced waiting time after loading will increase effective of the operation of the SEM

7

8 **R-4000-055 : Switching time between vacuum modes desire**

Description	VM
The switching time between high vacuum operation mode and low vacuum operation mode, and vice versa should be within 5 minutes.	D
Rationale	It is expected that for EDX measurements with charging samples, low vacuum operation mode will be used. If this switching takes longer then the stated time, this will impact the throughput of the SEM

9

1 **R-4000-060 : Switching time between vacuum modes manual actions desire**

Description		VM
The switching time between high vacuum and low vacuum mode, and vice versa should not require manual actions.		D
Rationale	Manual actions will increase the risk of operator errors, and will limit the option of automatization	

2

3 **R-4000-065 : Automated pump down and venting**

Description		VM
The SEM shall, after receiving the signal to pump-down or vent, execute all steps to needed to for fill this command without further instructions from the operator. Remark: it is expected that giving the instruction to pump down or vent can be done with a very simple instruction, like a button pump down or vent in the HMI.		D
Rationale	Automated pump down or venting will increase the safety of the machine because it prevents operator error. It also increases the ease of use of the SEM	

4

5 **R-4000-070 : Prevention against damage due to over- pressure**

Description		VM
The SEM shall prevent the system against damage due to over-pressure. I.e., source on at a too high pressure will impacting lifetime. A second example would be that during venting the entire vacuum vessel is set on an over-pressure resulting in, in example windows will burst Remark: as stated previously, TNO expects a COTS SEM, and assumes that the suppliers have adamant experience in manufacturing a save SEM. The proposed mitigations against the risks shall be stated in the tender document.		R
Rationale	Damage to the SEM most likely would result in unexpected maintenance required for the SEM, impacting the availability of the SEM. I worse case it could affect human safety, this is unacceptable.	

6

7 **R-4000-075 : Dry roughing pump**

Description		VM
The SEM shall use dry roughing pump(s) Remark: Dry rough pumps are considered roughing pumps that prevent oil contamination reaching the SEM, this could be by not having oil in the vacuum part of the roughing pump, or shielding this i.e. with N2 flow from the vacuum side of the pump		I
Rationale	In the case of a failure with a dry roughing pump no contamination can be introduced into the SEM. The current market of roughing pumps has a wide selection that would fulfill this requirement	

8

1 R-4000-080 : Turbo Molecular Pump (TMP) without oil, desire

Description		VM
The SEM should use a TMP without oil.		I
Remark: this may be achieved by using a magnetically levitated TMP		
Rationale	Although TNO would prefer a magnetically levitated TMP with respect to cleanliness in the SEM vacuum, it is for TNO unclear if this would impact the SEM performance, therefor this is stated a desired requirement.	

2

3 Facilities

4 This chapter describes all the requirements that are related to the VLL facility and the SEM. This goes
5 from mechanical and electrical interfaces to the clean room, or laboratory.

6 R-5000-005 : External resources specifications

Description		VM
The SEM system shall meet its requirements while complying to the following external resource specifications: - GN2 supply pressure = up to 6 bar(a) - CDA supply pressure = up to 7.5 bar(a) - Cooling water supply temperature <18 °C - Maximum cooling water return temperature = 30 °C - Maximum cooling water flow available is 500 l/hour - An electric power supplied of; 240 volt, 50 hrz, and/or 400 volt, 3 phase, 50hrz.		R
Rationale	The SEM will be located in the VLL building and thus should comply with its resource specifications.	

7

8 R-5000-010: Electric power connection fusing

Description		VM
The electric power connections of the SEM system shall have double poled fusing or circuit breakers (fuses placed in both the phase and neutral conductors).		I
Rationale	TNO safety standard.	

9

10 R-5000-015: Protected earth grounding

Description		VM
The SEM system shall be provided with at least one protected earth groundings to enable connection to protected ground connection in the VLL.		I
Remark 1: It is expected that each electric cabinet has a protected ground connection.		
Remark 2: Within the VLL dedicated grounding points are available.		
Rationale	TNO safety requirement.	

11

1 **R-5000-020: Power consumption during normal operation**

Description		VM
The power consumption of the SEM during normal operation shall not be more than 5 kW.		R
Remark: The power consumption and all electrical requirements shall be listed in the quotation of the supplier.		
Rationale	Available power in facility for SEM.	

2

3 **R-5000-025: Provided gas cleanliness**

Description		VM
The SEM shall be able to operate, to the stated requirements (for instance cleanliness) with a GN2 and XCDA quality provided by the VLL facility of 99.999% purity.		R
Remark: If a higher quality is required this may be solved by using end point filters located on the gas distribution boards. These end point filters are then part of the delivery of the SEM system. The tenderer shall put forward during PDR the expected lifetime of these end point filters.		
Rationale	99.999% gas quality is guaranteed by the VLL.	

4

5 **R-5000-030: Location of the roughing pump(s)**

Description		VM
The roughing pump(s) shall be located in the VLL corridor.		R
Remark 1: the supplier shall state the maximum distance that the roughing pump can be away from the SEM in the tender document		
Remark 2: the lay-out of the SEM in the VLL, will be agreed on in an interface control document during the PDR meeting		
Rationale	Reduction of noise and vibration in the clean room, also most likely needed for SEM performance.	

6

7 **R-5000-035: Roughing pumps - connection to exhaust**

Description		VM
The roughing pumps shall allow for connection to a central exhaust in the VLL building.		R
Remark: The SEM supplier shall state the flange type and dimensions of the pre-pump(s) in the ICD documentation.		
Rationale	Noise and contamination levels in the machine room and the cleanroom will be negatively affected when the roughing pumps are not connected to an exhaust.	

8

R-5000-040: Maximum weight

Description	VM
The floor load per 1 m ² of both the SEM and the support equipment shall not exceed 1000 kg.	R
Rationale	The stated value is the maximum value allowed floor load of the VLL building.

R-5000-045: Required volume claim

Description	VM
At the PDR, or preferably in the tender document, the supplier shall specify the required volume claim in the cleanroom and in the VLL corridor of the entire SEM system.	R
Rationale	Needed for preparation of the cleanroom and VLL corridor.

R-5000-050: Required volume claim for maintenance

Description	VM
At the PDR the supplier shall specify the required volume claim for maintenance	R
Rationale	Needed to prepare the cleanroom and VLL corridor.

R-5000-055: SEM electronics cabinet

Description	VM
All electronics shall be installed in an electronics cabinet.	R
Rationale	All electronics should be grouped together.

R-5000-060: Clean room conditions

Description	VM
The SEM system and the support equipment located in the cleanroom shall be compatible with operating under cleanroom conditions (room temperature 21 °C +/- 1 °C, humidity between 30% and 70%).	R
Rationale	SEM will be located in a cleanroom.

R-5000-065: VLL corridor conditions

Description	VM
The support equipment of the SEM system that is located in the VLL corridor shall be compatible with operating under the VLL corridor conditions (room temperature 15 °C to 30 °C, humidity between 30% and 70%).	R
Rationale	Expected worst case conditions in the VLL corridor. Normal temperature is similar to clean room conditions.

1 **R-5000-070: Cleanroom compatibility**

Description		VM
All external surfaces of the SEM shall be easily cleanable, i.e. smooth surfaces and no hidden areas.		I
Rationale	Ensure that the clean room is not contaminated by the SEM system.	

2

3 **R-5000-075: External cleanliness**

Description		VM
The external surface of the SEM and support equipment shall be free of grease, oils, and other manufacturing residues.		I
Rationale	Cross contamination should be prevented.	

4

5 **R-5000-080: Particle contamination on external surfaces**

Description		VM
The SEM and the support equipment shall be visibly clean, i.e. they shall have a Particle Area Coverage (PAC) of less than 250 ppm.		I
Remark 1: The SEM and support equipment may be cleaned by the supplier before entering the clean room.		
Remark 2: TNO believes that this requirement will be met if the supplier takes care to use smooth and easy to clean materials.		
Rationale	Realistic requirement for particle contamination on the outside of a chamber and support equipment.	

6

7 **R-5000-085: Restrict amount of air-cooled equipment**

Description		VM
The amount of active/forced air-cooled equipment needed for the SEM that is located inside the ISO 14644 class 6 cleanroom shall be kept to a minimum.		I
Remark: In case active/forced air-cooled equipment inside the cleanroom is needed to operate the system, this shall be listed and put forward by the supplier during PDR.		
Rationale	The flow of the air-cooled equipment can disturb the cleanroom flow conditions.	

8

9 **R-5000-090: Noise output cleanroom**

Description		VM
The noise output of the SEM system and support equipment located in the cleanroom shall be less than 75 dB(A) in the cleanroom		R

Remark: The preferred solution is to select equipment that produces less than the required 75 dB(A). Isolation or locating equipment in the VLL corridor is allowed.	
Rationale	It is expected that people are working close to the SEM for many hours. The lower the noise level, the better.

1

2 R-5000-095: Grouped cables

Description		VM
The cables both in vacuum and outside vacuum shall be grouped together as much as possible.		I
Rationale	Grouped cables decrease the risk of damage to a single cable and make routing easier.	

3

4 R-5000-100: Labelled cables

Description		VM
The cables outside vacuum shall be labelled		I
Rationale	Labelled cables will increase safety and decrease installation and troubleshooting time.	

5

6 Control software

7

8 TNO expects the SEM to be operated with a Windows 10 or 11 based operating system. TNO desires
9 that the operation of the SEM and EDX can be done remotely, with the exception of loading samples.
10 For this the SEM and EDX computers need to be integrated into the TNO network. The computers are
11 required to have a virus scanner.

12

13 In some cases TNO will export the measurement data (raw or processed images, raw or processed
14 EDX data, generated reports) to other network locations. Therefore, the measurement data should be
15 able to be copied or exported to other computers or network locations.

16

17 The software should be user friendly, meaning it should not take too long to be able to operate the
18 SEM at a basic level. Under user friendly TNO also considers ease of repeated measurements. Being
19 able to write a basic recipe and repeating it a number of times will save significant amounts of operator
20 time and reduce the chance of human errors.

21

22 R-6000-005 : Computer controlled SEM operation

Description	VM
All operations of the SEM system shall be computer-controlled.	D
Remark: After awarding the tender, TNO and supplier shall agree on the best way to configure and install one or multiple computers for the SEM and EDX software and how it should be integrated into the TNO network. This will be documented in the ICD.	

Rationale	The SEM contains multiple instruments that need to operate simultaneously.
-----------	--

1

2 R-6000-010: Computer username and password

Description	VM
The computer used for controlling the SEM shall use username and password to protect the SEM against unauthorized use.	D
Rationale	Untrained personnel must be prevented from operating the SEM.

3

4 R-6000-015: Multiple user profiles

Description	VM
The control system of the SEM system shall have at least four user profiles. Remark: It is expected that each operator shall be able to log in on their own user account, or profile, with their own user preferences in the SEM and EDX software.	D
Rationale	Each user has his/her own preferences, which can be loaded by logging into the system using their own credentials.

5

6 R-6000-020: Customizable GUI desire

Description	VM
The SEM software GUI should be able to be customized and saved per user profile.	D
Rationale	Customizable GUI will improve efficiency of the SEM users

7

8 R-6000-025: Navigation on sample

Description	VM
The SEM shall be equipped with a method to navigate across the loaded sample using an image of the loaded sample. Remark: it is expected that this at least can be done using a camera, see requirement R-6000-030	D
Rationale	The SEM user should be able to know where on the sample the electron beam is positioned.

9

10 R-6000-030: Camera on SEM

Description	VM
The SEM shall be equipped with a permanently installed camera that is able to obtain an image that can be used for navigation across the loaded sample.	D

Rationale	This camera can take the image is used for navigating over the sample, see requirement R-6000-025.
-----------	--

1

2 **R-6000-035: Navigation camera field of view**

Description	VM
The camera stated in R-6000-035 shall be able to make an image with field of view dimensions of 10 cm x 10 cm. Remark 1: the supplier shall state the field of view in the tender document Remark 2: Ideally imaging all the stated samples in D003 is preferred	D
Rationale	At least a 4" wafer should be fully imaged by this camera.

3

4 **R-6000-040: Navigation camera resolution**

Description	VM
The navigation camera image shall be able to resolve details on a sample of 0.1 mm or smaller for the defined wafer samples as stated in appendix D003.	R
Rationale	Small features should be visible, to aid the SEM operator navigating over the sample.

5

6 **R-6000-045: Use external images as navigation image desire**

Description	VM
The SEM software should be able to load an external image, to be used as navigation image (R-6000-025). Remark: expected formats are: .JPG, .PNG, .TIFF	D
Rationale	In case no acceptable image can be made using the navigation image camera.

7

8 **R-6000-050: Navigation image alignment**

Description	VM
The SEM software shall be able to perform an alignment procedure between the navigation image (R-6000-025) and the SEM position on the sample. Remark: This may be achieved by performing a 3 point alignment procedure, linking the images with the navigation image.	D
Rationale	Prevent mismatch between navigation image of sample and SEM position on sample.

9

1 **R-6000-055: Scan rotation**

Description		VM
The SEM shall be able to perform scan rotation, to align to features in the obtained image without having to physically rotate the sample stage.		D
Rationale	When the image can be rotated by any arbitrary rotation clockwise and counter clockwise, without the sample being physically rotated. This can be useful, for example to align patterns on a sample with the horizontal alignment of the SEM image.	

2

3 **R-6000-060: Scan rotation range and resolution**

Description		VM
Scan rotation (R-6000-055) shall be possible over 360 degrees.		D
Remark: It is expected that the scan rotation can be set with an accuracy of 0.1 degrees.		
Rationale	Accuracy and range of the scan rotation are needed for the type of samples TNO uses.	

4

5 **R-6000-065: Find back previous imaging locations**

Description		VM
The system shall be able to return to locations of interest, or locations where images were previously made, on a sample.		D
Remark: This may be done, for example, by saving a location of interest in a positions list embedded in the GUI.		
Rationale	After an experiment we need to make images on the same locations where imaged were made during pre-experiment SEM imaging, to be able to compare the pre- and post-experiment images.	

6

7 **R-6000-070: Export and import stage coordinate list desire**

Description		VM
A list of saved coordinates should be able to be exported and imported, for example in a text format file.		D
Remark: The coordinate list should at least consist of X, Y, Z coordinates. Preferable also rotation and tilt.		
Rationale	A position should be able to be found back to inspect on a later moment. Furthermore, for later analysis purposes it can be useful to have a list of coordinates.	

8

1 R-6000-075: Find back previous imaging locations on sample accuracy

Description		VM
The SEM shall be able to find back image locations made in a previous imaging session, with an accuracy of 10 um or better. Remark: This may be solved by for example setting up a custom coordinate system based on three easy to find markers on the sample, after which image locations expressed in this coordinate system can be saved.		T
Rationale	Find back micrograph locations before and after an experiment. The micrograph locations of pre-experiment imaging can then be found back during the post-experiment imaging.	

2

3 R-6000-080: Custom coordinate system desire

Description		VM
The SEM system should be able to set-up a custom coordinate system, which can be set-up based on one, two or three positions. Remark: see appendix D008 for the detailed description on the expected implementation		D
Rationale	In some occasions it is very useful to mimic the coordinate system of another experimental setup or material analysis tool. To the user it can then also be immediately clear at which location expressed in this other tool's coordinate system a certain feature is visible.	

4

5 R-6000-085: Perform basic scripting

Description		VM
It shall be possible to perform basic scripting, either with a simple scripting language, C++ or Python, or using visual scripting (e.g. using blocks with certain functions and parameters). Remark: A script or recipe should be able to be saved and loaded, such that it can be used multiple times.		D
Rationale	Scripting of repetitive tasks will significantly reduce operator time and reduce the chance of making human errors.	

6 R-6000-090: External control of SEM desire

Description		VM
The SEM should be able to be controlled by an external programming script using a programming language, such as Python or C++.		D
Rationale	Use the SEM as part of a programming script, to use the SEM, obtain data, and process the data further.	

7

1 **R-6000-095: Stitched imaging**

Description	VM
The system shall be able to make a large area, high resolution image. Remark: This may be achieved by performing stitched imaging, in which an area is defined and a resolution is set, after which the SEM will acquire the necessary micrographs and combine these in one large image.	D
Rationale	Acquire large area high resolution micrographs.

2

3 **R-6000-100: 3D image acquisition desire**

Description	VM
The system should be able to process micrographs made with a segmented detector, to acquire a 3D reconstruction. Remark: This may be done using external software, which will be supplied with the system.	D
Rationale	Obtain depth information of sample features.

4

5 **R-6000-105: Simple analysis tools**

Description	VM
The SEM software shall be able to perform various analyses on the acquired image data, such as: - Measuring length of features - Counting the number of particles - Determine size and surface area of particles Remark: In the tender document it shall be stated which analysis tools are available.	D
Rationale	Will add value to the obtained SEM data by supplying a complex analysis.

6

7 **R-6000-110: Save analysis data**

Description	VM
Analysis data shall be able to be saved in a file format, such as PDF, DOCX, or similar. Remark: In the tender document it shall be stated what filetypes are available.	D
Rationale	Saving analysis data in a file makes it possible to distribute results in a reliable way.

8

9 **R-6000-115: Customizable data bar**

Description	VM
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The SEM software shall allow for customization of the micrograph data bar, including the ability to select which parameters are displayed and the order in which they are presented.		D
Rationale	Important parameters should be visible in the image to give context for the viewer.	

1

2 R-6000-120: Save and load data bar settings desire

Description		VM
Users should have the ability to save and recall custom data bar configurations for future use.		D
Rationale	Data bar settings may vary per SEM measurement. Loading certain data bar pre-sets will save time and reduce the chance of human errors.	

3

4 R-6000-125: SEM remote operation

Description		VM
The SEM shall support remote operation.		D
Remark: Protocol to be determined after awarding tender. Minimum requirements are Microsoft Windows 10 with up to date anti-malware software and firewall.		
Rationale	Efficient use of the SEM will be increased if the operator can control the SEM remotely.	

5

6 R-6000-130: SEM operation single operator

Description		VM
The SEM shall be able to be safely operated by a single person.		D
Rationale	Efficiency and cost-effectiveness of SEM will be increased if it can be operated by a single person.	

7

8 R-6000-135: SEM human machine interface

Description		VM
The SEM shall be delivered including a specialised input unit, that will control the most basic parameters of the SEM, such as magnification, zoom, astigmatism controls.		D
Rationale	Efficiency and cost-effectiveness of SEM will be increased if it can be operated with an optimized HMI.	

9

10 R-6000-140: EDX colour element mapping

Description		VM
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The SEM EDX system shall be capable of producing element colour maps, which display the distribution of elemental composition within a sample by assigning each element a unique colour.		D
Remark: expected is that TNO can assign a colour to an element and can change this freely. If this is not possible, this shall be stated in the tender document.		
Rationale	Element colour maps are a very powerful representation of measured data.	

1

2 R-6000-145: SEM software display operating parameters

Description		VM
The SEM software shall display the key operating parameters on a dedicated part of the GUI.		D
Remark 1: The SEM supplier shall put forward in the tender the proposed key parameters that are shown and logged.		
Remark 2: Key operating parameters are to be discussed and agreed on after the tender is awarded.		
Rationale	Necessary for convenience of operation.	

3

4 R-6000-150: SEM software system logging desire

Description		VM
The SEM should ideally log all operations in a system logfile.		D
Rationale	To be able to trace back when certain actions were performed, which parameters were used, or check system performance and usage.	

5

6 R-6000-155: Measurement data file system information

Description		VM
When a micrograph is saved in 16-bit grayscale TIFF format, the file shall contain EXIF metadata, such as date and time created, accelerator voltage, magnification, stage coordinates, etc.		D
Remark: It is expected that other file formats, such as 8-bit grayscale TIFF and various JPG formats, will also contain EXIF metadata.		
Rationale	16-bit grayscale TIFF will be the preferred image file format. Including this information with this measurement data (16-bit TIFF file) is necessary for verification of the measurement.	

7

8 R-6000-160: SEM computer data transport

Description		VM
The SEM software shall enable transport of the data stored on the SEM computer to other storage locations.		D

Remark: Network shares are the expected destination of the data.	
Rationale	The generated data of the SEM must be able to be backed-up on the TNO network shares

1

2 R-6000-165: Abort button

Description		VM
The SEM software shall feature an abort button which stops immediately all motion, and will stop immediately the SEM measurement. After the abort button is activated the SEM will await new commands.		D
Remark: This button shall not power the SEM down.		
Rationale	Necessary for remote operation of SEM, convenience of operation and, sample safety.	

3

4 R-6000-170: Imaging file name desire

Description		VM
The SEM software should enable an easy to program file name, for saving micrograph images, with options like automatically adding relevant imaging information, e.g.: - Magnification - Accelerator voltage - Stage coordinates Remark: The tender document shall provide the level of easy naming of files, including all options to add to the filename.		D
Rationale	Easy naming of imaging names will reduce the risk of naming errors, and will reduce the work load of the operator. Furthermore, image files with information in the names will make searching for scientists much easier.	

5

6 R-6000-175: SEM control with gloves

Description		VM
The control of the SEM shall function while operating it with non-conductive gloves.		D
Rationale	The SEM could be located in a cleanroom environment, therefore the operators will wear gloves.	

7

8 R-6000-180: Software to be delivered

Description		VM
The SEM shall be delivered with all the installation software required to (re-)install the control system of the SEM.		R

Remark 1: This includes all the programs installed in the PC and the PLC (if applicable). Remark 2: The installation process shall be documented in a manual that is part of the data pack to be delivered.	
Rationale	TNO should be able to (re-)install the control software if this is required after losing the control software, e.g. in case of hardware failure.

1

2 R-6000-185: Control interface user friendly

Description	VM
It shall be possible to perform basic operations with the system after three days of instructions. Remark 1: The supplier shall put forward in the tender document the number of days that are needed for <u>initial</u> instruction. Remark 2: The supplier shall put forward in the tender document a relevant example of the control interface screen, e.g. by using print-screen(s).	D
Rationale	Operation of the SEM system must be simple and safe. User friendly software will increase safety and efficiency.

3

4.3.141 Generic requirements

5 This chapter states the generic requirements for the SEM, from safety to documentation. Each
6 paragraph starts with a small introduction.

7

8

9 The following section describes the requirements on documentation that needs to be provided before,
10 during and after the installation of the SEM.

11 R-0000-020: Installation requirements

Description	VM
The PDR documentation shall include all the documentation/information necessary for preparing the installation of the SEM. Remark: This includes for instance fitting diameters, electrical connections, floor load, required space for transportation, EMC fields, hoisting points etc.	R
Rationale	Necessary to verify that TNO is able to provide required supplies.

12

13 R-0000-025: Specification of external resources

Description	VM
At the PDR, or preferably in the tender document, the supplier shall specify the required external resources for the SEM system. Remark 1: TNO expects to be able to provide all required external resources. Remark 2: Information provided in the tender document shall at least include ball-park figures of: o electrical power requirements;	R

- o power consumption; - o cooling requirements; - o required mass flow rates of gasses (such as nitrogen and compressed dry air); - o liquids.	
Rationale	Information is needed to facilitate the SEM.

1

2 R-0000-030: Output to VLL

Description	VM
At the PDR, or preferably in the tender document, the supplier shall specify the SEM generated output to the cleanroom or lab. Remark 1: It is expected that the SEM system will produce heat, magnetic fields, etc., the amount and source of which shall be stated. Remark 2: TNO will inspect the supplied information and expects that that none of the output will be unacceptable for the environment. If an output to the environment is unacceptable, a method of mitigation shall be discussed between both parties.	R
Rationale	Information needed to prepare the VLL cleanroom.

3

4 R-0000-035: Documentation of third party hardware

Description	VM
The supplier shall deliver certificates, CE declarations of conformity, and manuals for all the third party hardware that is part of the SEM system. Remark: Delivery of documentation is expected during FAT.	I
Rationale	TNO quality requirement.

5

6 R-0000-040: CE certification

Description	VM
The SEM shall be CE certified.	I
Rationale	Safety and quality of SEM.

7

8 R-0000-045: SEM manual

Description	VM
The SEM shall be delivered with a manual. This manual shall include the necessary drawings and electric layouts to perform simple troubleshooting and shall include basic operation instructions.	I
Rationale	Necessary for simple trouble shooting or for operating the SEM.

9

1 **R-0000-050: Certificates**

Description		VM
The supplier shall document all the certificates.		I
Remark 1: TNO expects certificates on: - Calibration certificates (if applicable); - Specifications and manuals of COTS equipment; - Outcome of the review of the used materials against the forbidden material list Remark 2: Delivery of documentation is expected during FAT.		
Rationale	Certification of the used materials and equipment may be required by the customers of TNO.	

2

3 **R-0000-055: Drawings to be delivered**

Description		VM
The SEM shall be delivered with <u>all relevant</u> STEP files and "as built" drawings.		I
Remarks 1: It is expected that it will include, relevant mechanical drawings (interfaces, sample holder), electric, gas, water, etc.		
Remarks 2: Delivery of documentation is expected during FAT.		
Rationale	These drawings are needed for documentation and trouble shooting.	

4

5 The following section describes the requirements on the SEM safety and used standards.

6 **R-0000-060: Used standards**

Description		VM
The SEM system design and implementations shall implement the relevant and applicable legislation and regulations in the following order of preference if not already specified in this requirements document. - International standards; - European standards; - Commercial standards; - National standards; - Manufacturing standards, newly developed standards		R
Rationale	TNO safety requirement.	

7

8 **R-0000-065: Radioactivity**

Description	VM
The SEM system shall comply with all radioactive codes and regulations in order to be allowed to be installed and operated in the Netherlands.	R
Remark: If any actions are needed on the facility side, like a permit, the supplier shall inform TNO that this is needed before PDR.	

Rationale	Safety requirement within TNO
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R-0000-070: FMEA

Description	VM
The supplier shall perform an FMEA and shall share the outcome with TNO. Remark 1: It is expected that TNO is asked for input to the FMEA in an early stage of the process. Remark 2: TNO expects that identified critical failures are safe-guarded with at least two independent mitigation methods.	R
Rationale	An FMEA is required to close out some of the requirements, and is needed to increase the safety of SEM, and or the samples that are loaded into the SEM.

R-0000-075: SEM emergency stop button

Description	VM
The SEM shall have at least one physical emergency stop button. Remark 1: This emergency stop will initiate the EMO state. Remark 2: The location of the emergency stop button shall be agreed on with TNO.	D
Rationale	Machine and operator safety.

The following section describes the requirements during SAT.

R-0000-080: Functionality during SAT

Description	VM
The SEM shall be fully functional during SAT. Remark 1: The supplier shall provide a validation protocol for SAT at least two months before SAT. Remark 2: The supplier shall put forward what is expected from TNO during SAT at least two months before SAT.	D
Rationale	Needed for successful outcome of SAT test.

The following section describes the requirements for the SEM during external and internal transport.

R-0000-085: Transport to TNO

Description	VM
The SEM supplier shall be responsible for the transport of the entire SEM system from their facility to the VLL building, according Incoterm Delivered Duty Paid (DDP) 2020.	R
Rationale	Part of the delivery.

1 **R-0000-090: Transport inside VLL**

Description		VM
TNO will arrange and bear the costs of the transport of the SEM system from outside the VLL building to its final location inside the VLL. The supplier shall be present during this transport, and shall act actively, in case the supplier deems this transport to be unsafe for the SEM system.		R
Remarks 1: Since at time of transport the SEM is not yet the property of TNO, both the supplier and TNO share the responsibility that this transport will not damage the SEM system.		
Remarks 2: The installation/assembly of the SEM system remains the responsibility of the supplier.		
Remarks 3: On request, TNO can supply information about companies that have permission and experience to work in the VLL building concerning installation work and transportation.		
Rationale	Due to local regulations, TNO deems it not feasible for the supplier to arrange the transport from outside of the VLL building into the VLL building and to the final location. Therefore, TNO decides to take the responsibility of arranging this.	

2

3 **R-0000-095: SEM external volume claim during transport**

Description		VM
During transport the SEM shall fit in the volume claim of 1.8 by 1.8 by 2.0 meters.		R
Remark: During transport the SEM may be delivered in several parts, as long as the available space in the clean room is sufficient for assembly.		
Rationale	Available transport volume in laboratory.	

4

5 The following section describes the requirements on software updates and licence cost.

6 **R-0000-100 : Windows update**

Description		VM
The control software shall support, free of charge, all future versions of windows during the expected lifetime of the SEM.		R
Remark: the free of charge is as long as no hardware upgrade is needed.		
Rationale	With the expected lifetime of the SEM it can be expected that several new windows versions can be released. To ensure safety of the IT infrastructure the SEM control PC might be required to update to the latest version. When this is required it is vital for the IT infrastructure that this upgrade is performed, not doing this will result in the SEM being disconnected from the IT infrastructure hindering operation of the SEM.	

7

1 **R-0000-105: Control software updates**

Description		VM
The supplier shall update the software free of charge up to the minimum expected lifetime of the SEM. Remark: if a hardware update is needed for the software update, this option will be presented to TNO, and if TNO wishes to perform this hardware update, the no additional license fee remains in place. The hardware cost shall be marked conform prizes.		R
Rationale	TNO expects that the SEM is delivered with a software that in time will be updated with new features or bugfixes. TNO demands to receive these without any charge.	

2

3 **R-0000-110: License costs**

Description		VM
The offer includes all possible software licence fees, for all required applications, including all options and updates, without any limitation, for the minimum expected lifetime of the SEM.		R
Rationale	TNO is not willing to pay additional fees for applications / options or updates.	

4

5 The following section describes the requirements for training courses.

6 **R-0000-115: Advanced training**

Description		VM
Advanced application training for the SEM and selected accessories shall be given to TNO personnel on site, within 4 months after successful SAT. This training shall be given by an expert in the field of the supplier. Remark: it is expected that this training will be a 2- or 3-days training.		R
Rationale	Increasing the efficient and successful operation of the SEM.	

7

8 The following section describes the requirements for payment.

9 **R-0000-118: Payment conditions**

Description	VM
Terms and conditions of payment • 20% at order, after receipt of a bank guarantee covering 80% of the total amount; • 20% after Critical Design Review (CDR); • 40% after delivery and visual inspection at location TNO Delft. • 20% after installation and commissioning On-site and Site Acceptance Test (SAT) including test periods, approved by TNO, Management Nano Instrumentation and Procurement. At this moment TNO will return the bank guarantee. Remark 1: The Tenderer to whom the Contract will be awarded must provide a bank guarantee to TNO, covering 80% of the total price. The Bank guarantee and the bank who issues the Bank guarantee have to be approved by TNO (minimal A rating). TNO must have the right to draw the	R

bank guarantee in any and all cases where Tenderer falls short in fulfilling its obligations under the Contract. The validity of the bank guarantee may not expire until approval of the SAT by TNO Management and Procurement. Remark 2: please note, that approving the CDR this does not mean that TNO will take final responsibility if during SAT it is found that the system does not meet the minimum requirements. TNO will at all times hold Tenderer ultimately responsible for delivering an single-photon detector in accordance with the requirements as stated in this Tender.	
Rationale	Clear understanding of when TNO will proceed with payment.

1

2 4.3.1.2 Options

3 TNO expects that several options can be offered with the SEM, the following requirements are
4 applicable for the options that can be offered with the SEM. As stated in European public tender of the
5 SEM, the proposed options will not influence the outcome of the awarding, but after awarding could be
6 added to the quotation of the winning tender.

7

8 Proposed options are in example:

- 9 - Load lock
- 10 - Sample holders for stated samples in Appendix D003
- 11 - Cold trap
- 12 - STEM

13

14

15 R-0000-120: List available options

Description		VM
The supplier shall list the available options including the cost of each item individually.		R
Rationale	For fair comparison, an option may not affect (the awarding of) the tender.	

16

17 R-0000-125: Not affecting the performance of any other requirement

Description		VM
The stated option(s) shall not affect the required performance / the compliance, with any other requirement stated in this document.		D
Rationale	Proposed options shall not affect the stated requirements or preferences.	

18

19 R-0000-130: Clear description of performance of the options

Description		VM
The supplier shall put forward the relevant performance parameters of each option. If the option is selected, this stated performance will become a requirement that shall be met.		R

Rationale	To not limit the number of options that can be offered, TNO does not write down the performance requirements for the options. Some foreseen options are presented in the product tree.
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The following requirements are stated to ensure to receive a response from the supplier. As stated, options are not a part of the awarding of the tender.

R-0000-135: Option for load lock

Description	VM
The SEM supplier shall state if the SEM can be equipped with a load lock, and if so, which of the samples can be loaded from appendix D003 and D004.	R
Rationale	A load lock can decrease the time to load a sample, and increase the vacuum quality of the SEM.

R-0000-140: Option dedicated sample holders appendix D003 samples

Description	VM
Requirements R-3000-065, R-3000-070 and Preference R-3000-075 aim for easy, and speedy loading of the standard samples, stated in appendix D003. The supplier shall state all standard sample holder available and mark the sample holders that can be used to load the samples stated in appendix D003, including prizes. Next to standard sample holders, and if needed, the supplier shall state the cost for dedicated sample holders to load the stated samples, stated in appendix D003 Remark: TNO expect that wafer, reticle and a multipurpose sample holder is in the default sample holder catalogue are available.	R
Rationale	Efficiency and sample safety increases when sample holders are present that enables simple loading of standard samples.

R-0000-145: Option cold trap

Description	VM
The SEM supplier shall state if a cold trap is of benefit for TNO's anticipated usage of the SEM.	R
Rationale	A cold trap could catch contaminants in the SEM vacuum chamber and reduce carbon formation on analysed surfaces.

4.4 Precedence of requirements

N/A

4.5 Criticality of requirements

N/A.

5 1 Requirements traceability

2 5.1 Requirements traceability

3 N/A

4 5.2 List of safety-related requirements

5 N/A

6 5.3 List of security-related requirements

7 N/A

6 1 Notes

2 none