KALIBREERIMISTUNNISTUS
CALIBRATION CERTIFICATE

EAK EN ISO/IEC 17025 K025

Tunnistuse nr ja kuupäev: *Certificate No and Date:*	K8-009-25 / 2025-02-12
Tellimuse nr ja kuupäev: *Order No and Date:*	T8-024-24 / 2024-10-14
Tellija: *Customer:*	School of Marine Sciences, University of Maine 5706 Aubert Hall, Orono, ME 04469-5706, USA
Mõõtevahend: *Measuring instrument:*	Hyperspectral radiometer
Tootja: *Manufactured by:*	Satlantic Inc., Canada
Tüüp: *Type:*	HyperOCR
Seerianumber: *Serial number:*	302
Kalibreeritud: *Date of Calibration:*	2024-10-31
Meetod: *Method used:*	M805:28.02.2022 – Calibration of radiometers. Radiance

Allkirjad:
Signatures:

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Labori juhataja *Head of Laboratory*

Ilmar Ansko
Koostaja(d) *Compiled by*

Dokument koosneb kalibreerimistunnistusest 4 lehel ning on välja antud ühes (1) allkirjastatud eksemplaris.
The document consists of a Calibration Certificate on 4 pages in one (1) signed copy

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1. Kalibreerimisvahendid *Calibration equipment*

1. Quartz tungsten halogen lamp FEL-TO-1, Tartu Observatory, Estonia, S/N 7
2. Reflectance standard SphereOptics Zenith Lite 95%, S/N SG3151/1
3. Shunt resistor 10 mΩ, P310, S/N 009009
4. Multimeter (shunt and lamp voltage) Agilent 3458A, S/N MY45043877
5. Power supply for lamp L.O.T.-Oriel GmbH 69935 / LSN 597, S/N 166
6. Contactless distance probe LTO-1, (500.0±0.1) mm, S/N 001
7. Optical rail in light tight enclosure
8. Alignment laser XCL S/N 001

2. Jälgitavus *Traceability*

The measurement results are traceable to the units of SI through the standards of national metrology institutes: the quartz tungsten halogen lamp is calibrated at Tartu Observatory and traceable to MIKES-Aalto MRI (Finland) and multimeter Agilent 3458A at AS Metrosert (Estonia). Temperature and distance measurements are traceable to corresponding national standards of Metrosert Ltd. (Estonia).

3. Kalibreerimisobjekti kirjeldus *Description of the calibration object*

The calibrated spectrometer was a Satlantic HyperOCR radiance hyperspectral radiometer based on a Zeiss Monolithic Miniature Spectrometer (MMS-1) module in a water-tight housing. Zeiss MMS-1 with a concave holographic grating covers the spectral range of approx. (300..1150) nm, has a 3.3 nm wavelength step and spectral resolution of 10 nm. It contains a Hamamatsu silicon diode array sensor with 256 pixels. The optical input is formed as an input aperture in front of the fiber providing 23° field of view (FOV). The radiometer is equipped with an internal mechanical shutter to take the dark readings. Manufacturer has provided wavelength scale of the radiometer as a function of pixel number n = (2..256) with a spectral accuracy of 0.3 nm.

4. Kalibreerimismeetodi kirjeldus *Description of calibration method*

For determination of the spectral radiance responsivity, $R_L(\lambda)$, the radiometer was calibrated against a diffuse reflectance panel illuminated along the normal by a 1 kW quartz tungsten halogen (QTH) FEL source placed at the distance of 500 mm from the panel. The panel radiance was calculated as $L(\lambda)=E(\lambda)R(\lambda)/\pi$, where $E(\lambda)$ and $R(\lambda)$ denote the lamp irradiance at 500 mm and panel reflectance factor, respectively. The panel reflectance is calibrated by using the same geometry (i.e. 0°/45°). Three baffles (Ø60 mm aperture) were placed between the lamp and the reflectance panel in order to reduce the ambient stray light. A Ø60 mm shutter between the lamp and radiometer compartments was used during the background measurements. The lamp current and voltage were measured by using four-wire sensing, one pair of cables for feeding current to the lamp, and the other to measure the voltage drop on the lamp. The lamp current was stabilized using feedback from the calibrated shunt resistor. The operating conditions of the standard lamp are listed in Table 1. The lamp was allowed to stabilize for 20 min before the measurement started. The values of the lamp current and voltage as well as the ambient

temperature, relative humidity and atmospheric pressure were recorded continuously during the pre-heating and measurement phases.
A contactless distance probe, alignment jig, dual-beam self-balancing laser and mirrors were used to align the QTH lamp, the reflectance panel and the radiometer. The lamp and the panel were mounted on the optical rail; distance between the lamp socket's reference plane and the reflectance panel was measured using a special laser-guided distance tool, without mechanically touching the panel's surface. For angular alignment, the distance probe was removed and replaced with a self-balancing dual-beam laser. The lamp was aligned using a special jig, and the panel with the help of a mirror installed in the panel holder. Then, the mirror in the panel holder was rotated around it's vertical axis by 22.5° and the radiometer was installed along the 45° displaced laser beam using back-reflection from the radiometer's input window. Distance between the radiometer and the reflectance panel was chosen the shortest possible while avoiding instrument's shadow in the FOV (the chosen distance corresponded to the maximum output signal).
While measuring the panel radiance, 40 raw spectra (digital counts) were recorded using a fixed integration time, followed by the same number with the shutter between the lamp and the panel closed. The radiometer was configured to measure every fourth spectrum with the internal shutter closed. The process was repeated for different integration time. Data processing included the following steps: averaging of the raw spectra (with the nearest internal shutter measurement subtracted first), background signal subtraction, normalization to the common integration time, correction for the non-linearity, division by the panel radiance. Reflectance values were linearly interpolated to the radiometer's pixel central wavelengths (CWL) based on the calibration certificate of the panel.

5. Tulemused *Results*

The spectral responsivity coefficients are enclosed to the report as device calibration datafiles and a HyperCP datafile 'CP_SAT0302_RADCAL_20241031082634.txt'.

6. Mõõtemääramatus *Measurement uncertainty*

Uncertainty analysis has been carried out according to the ISO Guide to the Expression of Uncertainty in Measurement, and to the EA guide EA-4/02. The uncertainty estimate combines the contributions originating from the spectral irradiance of the standard QTH lamp, including data from the calibration certificate, from interpolation of the spectral irradiance values to the designated wavelengths of the radiometer, from instability of the lamp due to working time elapsed after calibration, from contribution to the spectral irradiance due to setting and measurement of the current of the lamp, from measurement of the distance between the lamp and the reflectance panel, from the panel calibration certificate, and from reproducibility of the alignment. Uncertainty contributions for the array spectroradiometer include repeatability and reproducibility of the lamp and dark measurements. The measurement results are valid at the time of calibration. The reported uncertainty does not include an estimate of long-time variations of the calibrated radiometer. The expanded uncertainties in the datafiles are given for the coverage factor of $k = 2$.

7. Keskkonnatingimused *Environmental conditions*

The environmental conditions in the laboratory during the measurements are given in Table 1.

Table 1. Environmental and operating conditions.

Ambient Temperature [°C]	21.0 ± 1.0
Relative humidity [%]	50 ± 5
Operating conditions of the standard lamp no 7	
Current [A]	8.1000 ± 0.0008
Voltage [V]	105.6
Burning Time [h:min]	00:55
Panel distance [mm]	500.0 ± 0.2
Panel illumination angle [°]	0
Measurement angle [°]	45