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ELT Ground Segment

WLRS-to-ISS

Laser Hazard Control Procedure

Subject:

Test Procedure

Author: U. Schreiber Institution: TUM
Prepared by: J. Eckl Institution: BKG

Agreed by: R. Much Organ. Unit: Institution: ESA

Document Change Record

Issue	Date	Affected Section/ Paragraph/Page	Reason for change/ Brief Description of Change
1	2020-03-03 2020-08-12 2023-02-16	All All	Initial version Final version Section 9.3 and 9.5

LIST OF ABBREVIATIONS

WLRS	Wettzell Laser Ranging System
SLR	Satellite Laser Ranging
LLR	Lunar Laser Ranging
ELT	European Laser Timing (Time transfer Package)
MPE	Maximum permissible Energy
ACES	Atomic Clock Ensembly in Space
ISS	International Space Station
TC	Test Conductor
QA	Qualtity Assurance Representative
BKG	Bundesamt fuer Kartographie und Geodaesie
TUM	Technische Universitaet Muenchen
HiQ	Company which built the Laser Oscillator
Innolas	Company which built the Laser amplifier
T/R	Transmit Receive Switch, a unit which either links the Laser or the Detector to the Telescope Port
TRR	Test Readiness Review

1. Introduction

This document describes the procedure to test and verify the safety measures that have been implemented to ensure that the laser power of the SLR system "Wettzell Laser Ranging System" (WLRS) always stays below the maximum permissible energy exposed to the eye of 7.7e-8 J (based on 5 pulses per 0.25 s) at the ISS for the time transfer operation to the ELT package onboard the ISS Columbus module. This is the condition for the crew looking at the laser beam with a telescope of an aperture of up to 400 mm diameter.

The test described in this procedure is intended to close the following verifications from the Unique Hazard Report ACES-15-WETTZELL:

1.1.3 Functional Test confirming Laser Amplifier Power OFF in case of ELT Mode selection
1.2.3 Functional Test confirming Beam Blocking Device always engaged in ELT Mode except when optical configuration bypassing the Laser Amplifier and Divergence setting to 200µrad is established
1.3.2 Functional Test confirming ISS target data forwarding to target database disabled except for ELT Mode

During the time of the ACES project there may be system modifications that have an effect on the laser eye safety for the ISS tracking. The here reported tests will be repeated when modifications related to the laser safety have been implemented.

2. APPLICABLE DOCUMENTS

- **AD1:** ESA-HRE-ACES-RP-0001, WLRS to ISS - Installation Report , issue 1
- **AD2:** ESA-HRE-ACES-RP-0002 , WLRS to ISS - Installation Report Addendum, issue 1

3. TEST CONFIGURATION

The WLRS is operated in various SLR projects, therefore it can be operated in two different configurations, namely a low power configuration A and a high power configuration B, with configuration A the standard configuration. To the naked unaided eye of ISS crew, both configurations are eye safe with an exposure of 4e-12 J for configuration A and 4e-10 J for configuration B. The sole purpose of this safety test inspection is to confirm that the laser power amplifier is powered off and physically separated from the laser beam path, when ranging to the ISS. Conversely, it verifies that ranging to the ISS is not accidentally possible when the laser amplifier is in configuration B.

This document is based on the system configuration as defined in the Installation report **[AD1]** and the addendum **[AD2]**

Configuration B includes the power amplifier as one element of the transmitter chain as indicated in fig. 1.

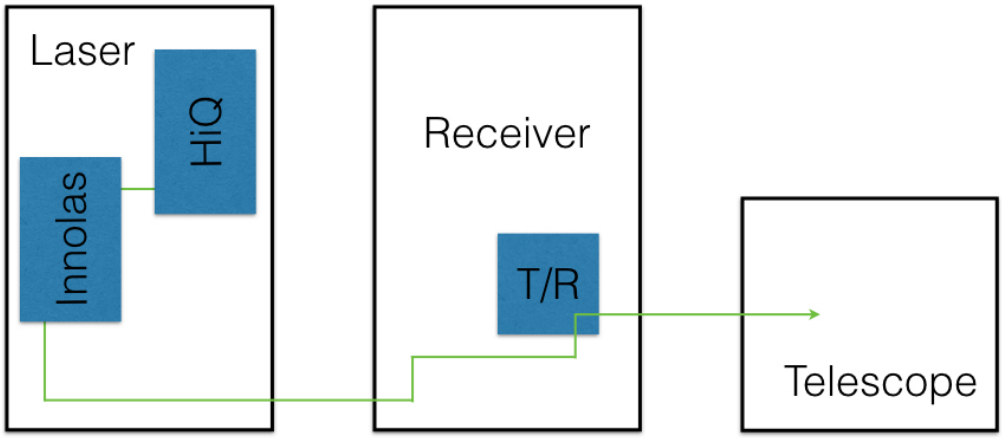


Fig. 1: *Block diagram of the WLRS with the transmit laser path indicated.*

Configuration A: The diagram shows how the laser amplifier is bypassed. In order to initiate ranging, the Innolas amplifier has to be powered off. Furthermore the beam path is modified by motor driven mirror stages to alter the laser beam path, as shown in fig. 2, locations A and B. A combination of 2 dichroic mirrors is shifted into the beam path to ensure radiation on 532 nm only (E). A beam power measurement system is controlling a beam block to make sure the beam power stays below the limit (C). The beam expander is commanded into the highly divergent position (D). All these functionalities are controlled by a chain of micro-switches. Which are closing when the required position is achieved. Any single item failing to achieve its functionality is enough to reliably disable the accidental transmission of the laser beam.

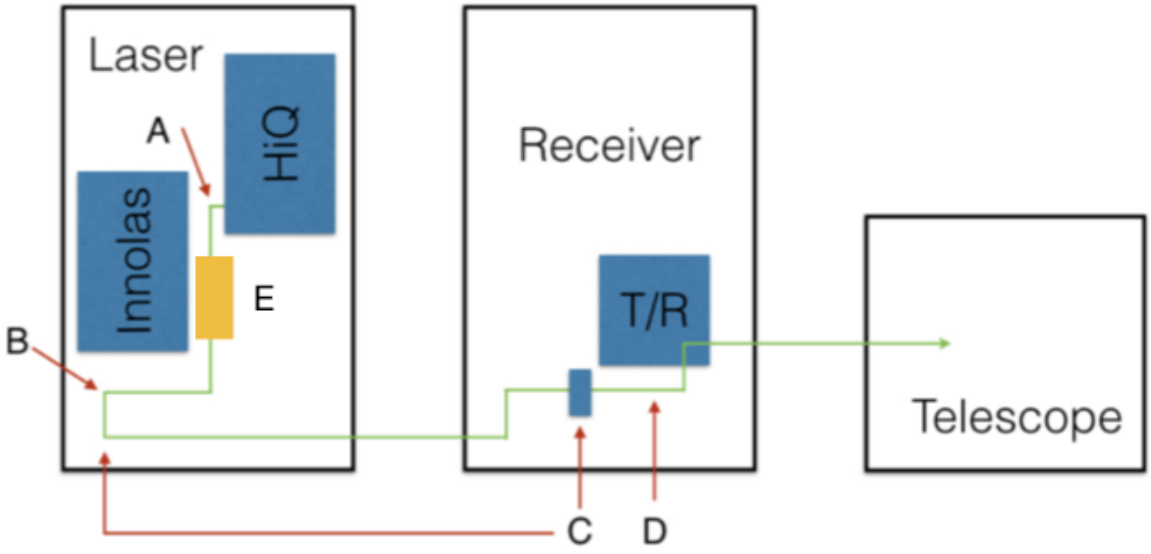


Fig. 2: *Modifications to the optical path and active safety features used in the low power mode.*

4. OBJECTIVE

This test procedure specifies the test setup, the work flow and related test sequences for the WLRS-to-ISS laser hazard reduction test. The test covers the correct operations of the software and hardware methods described in the Hazard Report ACES-15-Wettzell in the Configuration A) and B). This includes the correct operations of the hardware switch to switch between the conventional SLR/LLR ranging mode and the ELT ranging mode. In addition the test shall verify the correct operations of the sensors to ensure that the laser radiation is below the allowed limit given by the maximum permissible exposure to the ISS defined in the Hazard Report ACES-15-Wettzell. The following requirements shall all be met simultaneously during ranging in order to safely send laser pulses to the ISS:

a) The actual telescope pointing is within ±30 seconds of arc of the instantaneous target position as predicted by orbit calculations.
b) The Go/NoGo flag is true = set to Go
c) The divergence setting of the laser beam is set to high divergence values of 200 µrad or above. (see divergence setting description below)
d) The effectively generated laser energy at the input to the telescope is below 10 mJ for as long as tracking of the ISS lasts. (see laser intensity limitation below)
e) The wavelength of the tracking laser is exclusively 532 nm.

Since the WLRS is routinely operated in various, target dependent, ranging modes, this requires the following functions to be verified:

f) A mechanical switch, controlled by the observer, is installed to switch between the eye-safe ELT ranging mode and conventional SLR mode.
g) ISS ephemeris are available on GO state of the GO/NOGO flag only.
h) ISS ephemeris are available for one pass only when closing the mechanical switch in f).
i) Whenever ISS ephemeris are loaded and the pass is visible, the conditions a) to e) need to be in effect.

All eye-safety ensuring hardware switches and the laser is located in a closed restricted area. Operation procedures for SLR ranging require that the normal observer is not entering the restricted area. Service, development and maintenance activities are carried out by trained staff only and signed off by the laser safety engineer.

The test procedure outlined in this document will require to simulate the Go/NoGo flag and the ISS orbit. Physical tracking of the ISS itself is not required.

5. Quality assurance

Deviations, anomalies or discrepancies from the procedure will be clearly identified by time series and dedicated notes on the corresponding step number in section 9.5 of this procedure. The QA representative will be responsible for the entries/notes in the respective safety verification procedure protocol.

6. Personnel

The following personnel are permanently required for the performance of the test:

Geodetic Observatory Wettzell personnel:

- Test Conductor (TC)
- Quality Assurance Representative (QA)
- Procedure Author

In addition the following personnel may be present during the test:

- ACES authorized Representative(s)

The TC is responsible for the execution of the procedure under supervision of the QA representative. It is his duty to select the necessary qualified personnel for proper execution of the procedure and logging of the test results.
All personnel activities will be carried out under the responsibility and leadership of the TC. The safety requirements of the Geodetic Observatory Wettzell shall be met any time during physical presence at the Geodetic Observatory Wettzell.

7. Visusal Inspection of ACES Laser Eye Safety Installation

The target of the visual inspection is to verify the correct implementation of the intallations and laser power control features. An item by item identification of the respective features and elements as described in the implementation report are carried out (see checklist in 9.1).

7.1 Test Equipment

The following test equipment is required:

- 1 laser power meter PM160T-HP covering a range from 0.1 mJ – 120 mJ with a requirement of 10% accuracy
- 1 Oscilloscope Teledyne LeCroy Waverunner 9254 with a requirement of 10% accuracy

Remark: The tolerance of the specifications of the oscilloscope includes large margins, since even a 10 mJ laser power, which is one order of magnitude above the maximum specification of our laser is still compliant with the MPE. The measurements to be made are relative

measurements, using a linear relationship between the power measured and the voltage shown, hence absolute calibration oft he oscilloscope is not required. The test requires to verify that the light level (voltage) measured by a photodiode, placed behind one of the turning mirrors of the beam path, stays within a certain voltage range for the beam block to be in the non-blocked position.

The laser power meter shall be within the validity of its calibration at the time of the test

8. Additional precautions

During the eye-safety evaluation procedure listed in the safety verification procedure protocol below, unsafe laser powers at the telescope exit may not occur. Since some of the procedures of the test requires simulated ranging to the ISS as an additional safety precaution elements the laser dome shall be closed during the entire procedure.

9. Test and checkout sequence

9.1. Walk around Visual Inspection

Perform a walk around visual inspection to confirm that the test set-up is ready for test:

STEP		CHECK
1	Item by item identification of the respective features and elements as described in the implementation report is carried out	
2	Verify that the equipment is not damaged.	
3	Verify the equipment is installed correctly – no loose or hanging parts.	
4	Verify that miscellaneous tools and equipment not required for the test are removed from the test set-up area.	
5	Verify the sealing to prohibit accidental removal of the dichroic mirrors to prohibit transmission of the laser fundamental wavelength (1.064 nm).	
6	Verify that the dome is closed.	

9.2. Test readiness confirmation

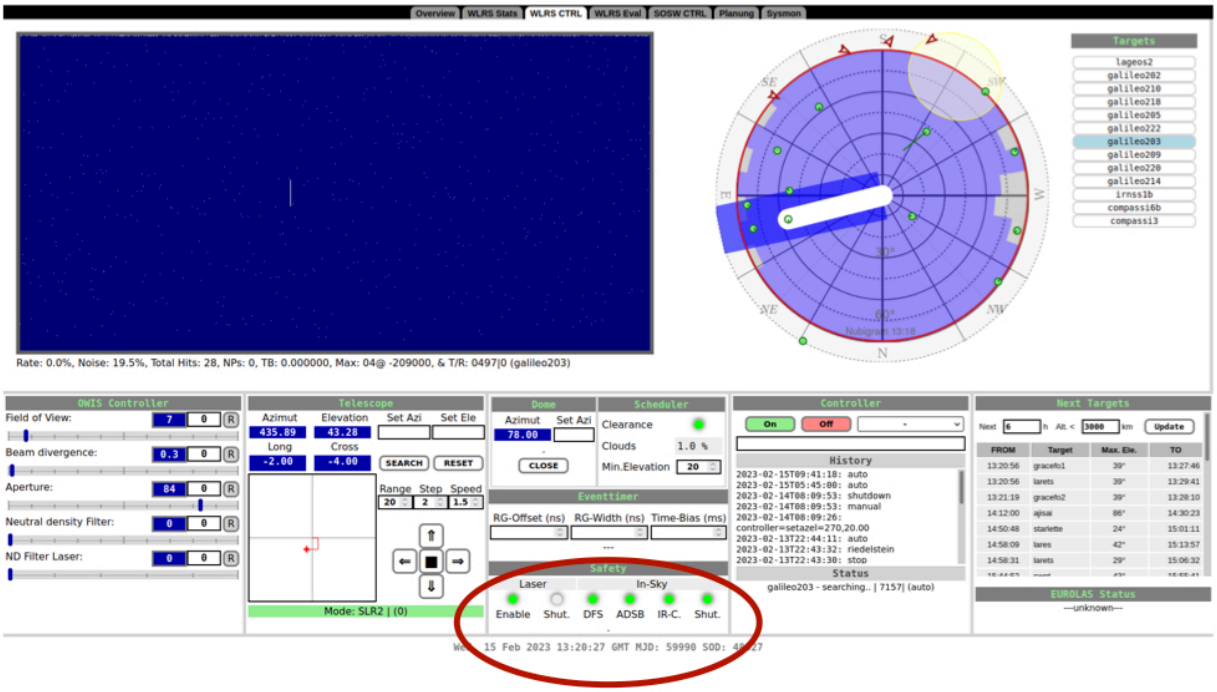
Test readiness will be confirmed based on the validity of the following prerequisites

STEP		CHECK
1	Documentation complete: The installation report and the addendum are available	
2	Personnel required present	
3	Test equipment complete as listed in Section 7.1	
4	Visual inspection satisfactory	
5	Dome closed	
6	The test set-up and configuration has been checked and found to be ready for test.	

9.3. VERIFICATION OF CORRECT SHUTTER POSITION

For most of the procedures in 9.5 the verification of the correct shutter position is required. This section will describe the corresponding procedure. At the relevant test execution procedure in 9.5 a reference to this sub-section is given. The verification of the correct shutter position is done visually at the observer room of the WLRS, as confirmed during TRR. In a first step, the state of the WLRS in-sky laser safety management system needs to be verified. This step is necessary to ensure that no other in-sky-safety method of the WLRS interferes with the test.

The digital LEDs of the Safety section of the WLRS Graphical User Interface indicate the status of the individual In-Sky-Safety methods (see figure below with the respective area marked). A green LED indicates clearance while a red LED means interruption from the corresponding method. During test conduction all LEDs must be illuminated green, giving clearance from all the other methods, except for the ELT safety method, which is independent. In the case, that there is interference from another In-Sky-Safety method, the corresponding test must be repeated. This is indicated by any of the LEDs being illuminated red.



To verify that the shutter is indeed at the right position, a second visual test is necessary. A camera in the Coudé-room of the WLRS provides an image of the reflection of the laser beam coupled into the WLRS telescope. When the laser shutter is out of the beam path, some scattered light is visible. This is highlighted by a red circle at the left hand side of the image below. On the right hand side the reflection is not visible. In this case the shutter is in the beam path. For verification of the correct shutter position, when the laser signal is blocked by one of the ELT safety methods no signal must be visible.

9.4. TEST WORKFLOW

1	Select proper ISS passages & activate ELT-RANGING MODE
2	Perform the tests 1 to 10 (executed via remote control)
3	Select other ISS passages & activate ELT-RANGING-MODE
4	Perform the tests 11 to 15 (executed by personnel inside the restricted area)
5	Select another potential ISS passage, but with GO/NOGO set to NOGO
6	Perform the test 16
7	Select another ISS passage, start tracking and change GO/NOGO to NOGO
8	Perform the test 17
9	Select another ISS passage
10	Perform the test 18
11	Select two consecutive ISS passages
12	Perform the test 19

9.5. TEST EXECUTION

Number	Description	Result	
		Accept	Reject
1.	Requirement for Configuration A) & B): **Scenario:** Laser Power Monitoring above laser pulse energy limit. **Description:** The Laser Power Monitoring device ensures that the laser pulse energy does not accidentally exceed the allowed energy limit. During ISS ranging the laser is always operated at its maximum pulse energy, since this does not exceed the limit. Therefore to test this item, the photodiode of the Laser Power Monitoring device has to be illuminated by an additional light source by the test personnel during a simulated ISS passage. **Procedure:** Measure beam power to verify compliance with the power requirements and then illuminate the photodiode with a torch by TC while ranging ISS. Compliance with MPE is given as long as the beam power stays below 7.7e-8 J to the eye at the ISS, which corresponds to 10 mJ of laser energy. This is far beyond the capability of our laser, hence we have set the threshold to 50% above the maximum obtainable energy of the HiQ oscillator of 1 mJ. **Result:** The laser beam block is blocking the beam path when the power monitoring threshold is exceeded. **Verification**: Described in 9.3		
2.	Requirement for Configuration A) & B): **Scenario:** Laser Power Monitoring at laser off state. **Description:** Switch the laser off during ISS ranging. Then the power supply of the laser beam block is open. **Procedure:** Switch off the laser via remote control while ranging ISS. **Result:** The laser beam block is blocking the beam path. **Verification**: Described in 9.3		
3.	Requirement for Configuration A) & B): **Scenario:** Dichroic mirrors to prohibit transmission of the laser fundamental wavelength are out of the beam path. **Description:** The dichroic mirrors are moved to the right position by a linear translation stage. The stage is remote controlled. For the test the translation stage is manually moved out of the beam path. As a result two micro-switches for monitoring the position of the translation stage are set to open state. The power supply of the laser beam block is open. **Procedure:** Move the linear stage with the dichroic mirrors out of the beam path by remote control while ranging ISS. **Result:** The laser beam block is blocking the beam path. **Verification**: Described in 9.3		

4.	Requirement for Configuration B): **Scenario:** INNOLAS post-Amplifier is disabled by utilizing the interlock functionality when ELT mode is activated. **Description:** When the ELT mode is activated, the INNOLAS post-Amplifier is interlocked. In addition to the modified beam path this ensures that the post-amplifier cannot be accidentally operated. **Procedure:** Punch the switch to ELT Mode and confirm that the post amplifier is off by visual inspection (attempt to switch it on). **Result:** The post-amplifier cannot be switched on.		
5.	Requirement for Configuration B): **Scenario:** INNOLAS Post-Amplifier bypass mirror 1 out of the beam path. **Description:** The bypass mirror is put into the beam path by a flip mount. This flip mount is remote controlled. For the test the flip mount is moved out of the beam path. As a result the micro-switch for monitoring the position of the flip mount is set to open state. Then the power supply of the laser beam block is open. **Procedure:** Move the bypass mirror 1 out of the beam path by remote control while ranging ISS. **Result:** The laser beam block is blocking the beam path. **Verification**: Described in 9.3		
6.	Requirement for Configuration B): **Scenario:** INNOLAS Post-Amplifier bypass mirror 2 out of the beam path. **Description:** The bypass mirror is put into the beam path by a flip mount. This flip mount is remote controlled. For the test the flip mount is moved out of the beam path. As a result the micro-switch for monitoring the position of the flip mount is set to open state. Then the power supply of the laser beam block is open. **Procedure:** Move the bypass mirror 2 out of the beam path by remote control while ranging ISS. **Result:** The laser beam block is blocking the beam path. **Verification**: Described in 9.3		
7.	Requirement for Configuration B): **Scenario:** The laser divergence control is not in the required position. **Description:** The laser divergence is set by a linear translation stage. This translation stage is remote controlled. For the test the translation stage is moved towards lower divergence values. As a result the micro-switches for monitoring the position of the translation stage are set to open state. Then the power supply of the laser beam block is open. **Procedure:** Set the divergence stage to a divergence of 190 µrad, which is the closest value below the allowed limit of 200 µrad, by remote control while ranging ISS.		

	Result: The laser beam block is blocking the beam path. **Verification**: Described in 9.3		
8.	Requirement for Configuration B): **Scenario:** The telescope pointing is not within +- 30 seconds of arc within the required position. **Description:** The offset between the current and the nominal position of the telescope is monitored by the WLRS control software. For the test the telescope is stopped during ranging the ISS. As a result the telescope pointing is not within the required limit. Then the power supply of the laser beam block is open. **Procedure:** Stop tracking of the WLRS telescope by executing the command 'tcu=stop' to the WLRS control system while ranging ISS. **Result:** The laser beam block is blocking the beam path. **Verification**: Described in 9.3		
9.	Requirement for Configuration B): **Scenario:** The ELT-Box is in an error state (red LED). **Description:** An error state of the ELT-Box is simulated by setting an artificial error. As a result conventional SLR is not possible. **Procedure:** SSH login to the ELT-Box and set artificial error by starting the program 'eltsafetyc'. On the following query of a satellite name enter: 'XXX'. This is an invalid name and causes an internal error. Try to perform ranging to an SLR target via the WLRS control software. **Result:** The ELT safety features are active for all states of the observer hardware switch. **Verification**: Described in 9.3		
10.	Requirement for Configuration B): **Scenario:** Failure of power supply of ELT-safety box. **Description:** Disconnect the power supply from the ELT-Box. **Procedure:** Disconnect the power supply cable from the ELT-Box while ranging ISS. **Result:** The ELT safety features are active for all states of the observer button. **Verification:** Described in 9.3		
11.	Requirement for Configuration B): **Scenario:** Accidental switching to non-restricted target mode during ELT ranging. **Description:** During ranging to the ISS the user hardware button is pressed. **Procedure:** Press the user hardware button to switch to conventional SLR state while ranging ISS. **Result:** The ELT safety features stay active for the remaining part of the satellite pass. **Verification:** Described in 9.3		

12.	Requirement for Configuration A) & B): **Scenario:** Cable failure (open circuit) between laser beam block and Laser Power Monitoring device. **Description:** Disconnect a cable connector from one plug of the ELT safety chain. Then the power supply of the laser beam block is open. **Procedure:** TC disconnect safety circuit cable from Laser Power Monitoring Device while ranging ISS. **Result:** The laser beam block is blocking the beam path. **Verification**: Described in 9.3		
13.	Requirement for Configuration A) & B): **Scenario:** Failure of power supply of Laser Power Monitoring device. **Description:** Disconnect the power supply of the Laser Power Monitoring device. Then the power supply of the laser beam block is open. **Procedure:** TC disconnect power supply cable from Laser Power Monitoring Device while ranging ISS. **Result:** The laser beam block is blocking the beam path. **Verification**: Described in 9.3		
14.	Requirement for Configuration A) & B): **Scenario:** Failure of power supply of laser beam block. **Description:** The power supply is driving the laser beam block via the ELT safety chain. Therefore a failure of the power supply is identical to an interruption of the ELT safety chain. To test this item, disconnect a cable connector from one plug of the ELT safety chain. (Identical to item 3.) **Procedure:** TC disconnect power supply cable from shutter while ranging ISS. **Result:** The laser beam block is blocking the beam path. **Verification**: Described in 9.3		
15.	Requirement for Configuration B): **Scenario:** INNOLAS Post-Amplifier power supply 1 is not shut down (key switch not turned off). **Description:** Power up the INNOLAS Post-Amplifier power supply 1. A relay output of the INNOLAS Post-Amplifier is set to open state. As a result the power supply of the laser beam block is open. **Procedure:** TC power up the INNOLAS Post-Amplifier 1 inside the restricted area while ranging ISS. **Result:** The laser beam block is blocking the beam path. **Verification**: Described in 9.3		
16.	Requirement for Configuration B): **Scenario:** INNOLAS Post-Amplifier power supply 2 is not shut down (key switch not turned off). **Description:** Power up the INNOLAS Post-Amplifier power supply 2. A relay output of the INNOLAS Post-Amplifier is set to open state. As a result the power supply of the laser beam block is open.		

	Procedure: TC power up the INNOLAS Post-Amplifier 2 inside the restricted area while ranging ISS. **Result:** The laser beam block is blocking the beam path. **Verification**: Described in 9.3		
17.	Requirement for Configuration A): **Scenario:** Ranging to ISS not possible when Go/NoGo flag is missing. **Description:** Press the mechanical user button to load ISS prediction data to the WLRS control software with no Go/NoGo flag present. The prediction data is not transferred to the ftp-server of the ELT-Box. **Procedure:** TC initiates tracking of ISS with no Go/NoGo flag by entering the target name, ISS, as a command in the operator interface of the SLR control software. **Result:** System denies ISS tracking, no ephemeris available		
18.	Requirement for Configuration A) & B): **Scenario:** GO/NOGO Flag in NOGO state at time of a user prediction request (button pressed). **Description:** Press the mechanical user button to load ISS prediction data to the WLRS control software when the GO/NOGO flag is in NOGO state. The prediction data is not transferred to the ftp-server of the ELT-Box. Caution: The GO/NOGO flag is provided externally from CADMOS and has to be in appropriate state. **Procedure:** GO/NOGO provider set the GO/NOGO-flag to NOGO prior to the selected ISS passage. **Result:** ISS predictions are not available, hence tracking is impossible. **Verification**: FTP login to FTP-Server of the ELT-Box and verify no prediction data present.		
19.	Requirement for Configuration A) & B): **Scenario:** GO/NOGO Flag in NOGO state during observation. **Description:** During ranging the ISS the GO/NOGO flag is set to NOGO. As a result the ELT-Box opens the power supply of the laser beam block via an electro-mechanical switch. **Procedure:** GO/NOGO provider set the GO/NOGO-flag to NOGO during the selected ISS passage. **Result:** The laser beam block is blocking the beam path. **Verification**: Described in 9.3		
20.	Requirement for Configuration A) & B): **Scenario:** GO/NOGO Flag goes to NOGO state right at the beginning of the observation. This tests that the response to the NOGO state is always immediate. **Description:** Right at start of ranging the ISS the GO/NOGO flag is set to NOGO. As a result the ELT-Box opens the power supply of the laser beam block via an electro-mechanical switch. **Procedure:** GO/NOGO provider set the GO/NOGO-flag to NOGO during the selected ISS passage.		

	Result: The laser beam block is blocking the beam path. **Verification**: Described in 9.3		
21.	Requirement for Configuration B): **Scenario:** The observer hardware switch is not at the required position before and during ISS ranging. **Description: S**elect an ISS passage. The observer hardware switch is not pressed for this passage. As a result the prediction data is not transferred to the ftp server of the ELT-Box. **Procedure:** Do not press the observer hardware switch before and during a selected ISS passage. **Result:** No ISS ephemeris available, the target is not available in the satellite list. **Verification:** FTP login to FTP-Server of the ELT-Box and verify no prediction data present.		
22.	Requirement for Configuration B): **Scenario:** Ranging consecutive pass available from prediction file. **Procedure:** Select two consecutive ISS passages, which are within 2 hours. In this case the prediction data from the data center usually contains a first and a second ISS passage. Make sure that the provided ephemeris file indeed contains ephemeris of the second passage. Track the first passage. The laser system may be switched off. After the first passage is finished put the hardware button into conventional SLR state. For the second passage do not press the hardware button again. **Result:** ISS target not available in satellite list on the WLRS control screen nor ephemeris are available until the observer hardware switch is activated. **Verification:** FTP login to FTP-Server of the ELT-Box and verify no prediction data present.		

9.6. TEST VERIFICATION CONFIRMATION

The test set-up and configuration has been checked and found to be ready for test.

Date: _____

_____ _____

(Test Conductor) (QUALITY ASSURANCE)