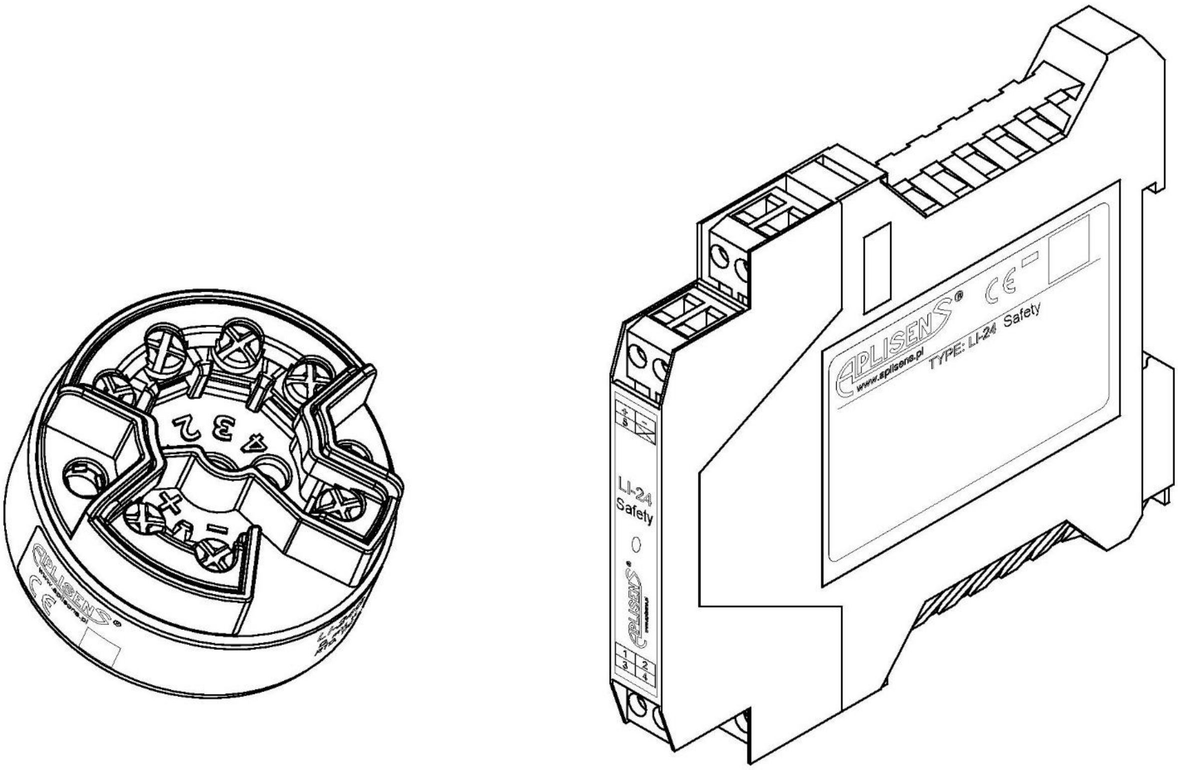
SIL SAFETY MANUAL

Temperature transmitters

LI-24L Safety
LI-24G Safety

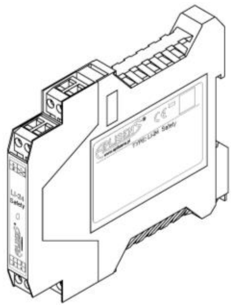


APLISENS S.A., 03-192 Warsaw, Morelowa 7 St.
tel. +48 22 814 07 77; fax +48 22 814 07 78
www.aplisens.com, e-mail: export@aplisens.com

PRODUCT CODE – see section 5.2 of the User's Manual.
The QR code or ID number identifies the transmitter and provides quick access to the following documentation on the manufacturer's website: user's manual, SIL safety manual, explosion-proof device user manual, declarations of conformity and copies of certificates

LI-24L Safety

ID:0003 0005 0003 0000 0000 0000 0001 26
https://aplisens.pl/ID/000300050003000000000000000126/00000000



LI-24G Safety

ID:0004 0006 0003 0000 0000 0000 0001 89
https://aplisens.pl/ID/000400060003000000000000000189/00000000

Symbols used

Symbol	Description
⚠	Warning to proceed strictly in accordance with the information contained in the documentation in order to ensure the safety and full functionality of the device.

BASIC FUNCTIONAL SAFETY REQUIREMENTS

⚠

The manufacturer will not be liable for damages resulting from incorrect installation, failure to maintain suitable technical condition of the device or use of the device other than for its intended purpose.

Installation should be carried out by qualified staff having the required authorizations to install electrical and I&C equipment. The installer is responsible for performing the installation in accordance with manual as well as with the electromagnetic compatibility and safety regulations and standards applicable to the type of installation.

The E/E/PE safety-related system should be configured in accordance with the application. Improper configuration may cause malfunction leading to a E/E/PE safety-related system failure or accident.

All safety and protection requirements must be observed during installation, operation and inspections of the E/E/PE safety-related system.

If the E/E/PE safety-related system is found to malfunction, disconnect it from the system and hand over to the manufacturer for repair.

In order to minimize the risk of malfunction and associated risk to staff, the E/E/PE safety-related system is not to be installed or used in particularly unfavourable conditions, where the following hazards occur:

- possible mechanical impacts, excessive shocks and vibration;
- excessive temperature fluctuation;
- water vapour condensation, dusting, icing.

⚠

For operation in functional safety loop LI-24L(G)-Safety transmitters shall be configured for the output signal of 4…20 mA. HART protocol can be used for diagnostics and transmitter configuration at a work station. After configuring and commissioning the functional safety system, use only the analogue current output signal. For safety reasons, access to the transmitter enabling modifying settings by unauthorised access must be prevented. The transmitters can be protected by software features from settings change.

Changes made to the manufacturing of products may be introduced before the paper version of the manual is updated. The up-to-date manuals are available on the manufacturer's website: www.aplisens.com.

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SIL DECLARATION OF CONFORMITY

Document number EN.DZ.LI.24.L.SIL.ID.REV1

Manufacturer: **APLISENS S.A.,**
Morelowa 7 St., 03-192 Warsaw

Declare with full responsibility that:

rail-mounted smart temperature transmitters
LI-24L Safety ID: 0003 0005 0003 XXXX XXXX XXXX XXXX XX[1)]

[1)] X in the ID code is manufacturer's indication not related to the certificate

meet the requirements of standards:
PN-EN 61508:2010 Part 1÷7
PN-EN 61511-1:2017-07 + PN-EN 61511-1:2017-07/A1:2018-03
PN-EN 62061:2008 + PN-EN 62061:2008/A1:2013-06 + PN-EN 62061:2008/A2:2016-01

Configuration	λ_{total} FIT	λ_{NE} FIT	λ_{SD} FIT	λ_{SU} FIT	λ_{DD} FIT	λ_{DU} FIT	SFF %	DC %	MTBF
1 RTD 2p	721,502	219,665	38,550	11,643	425,222	26,422	94,735	94,150	$1{,}386\times10^6$ h 158 Yrs
1 RTD 3p	721,502	218,845	38,550	11,643	426,042	26,422	94,744	94,160	$1{,}386\times10^6$ h 158 Yrs
1 RTD 4p	721,502	218,025	38,550	11,643	426,862	26,422	94,752	94,171	$1{,}386\times10^6$ h 158 Yrs
2 RTD 2p	721,502	218,025	38,550	11,643	426,862	26,422	94,752	94,171	$1{,}386\times10^6$ h 158 Yrs
2 RTD 3p	721,502	216,385	38,550	11,643	428,502	26,422	94,769	94,192	$1{,}386\times10^6$ h 158 Yrs
1 TC no CJC	721,502	220,905	38,550	11,643	423,982	26,422	94,722	94,134	$1{,}386\times10^6$ h 158 Yrs
1 TC int CJC	721,502	218,545	38,550	11,643	426,132	26,632	94,705	94,118	$1{,}386\times10^6$ h 158 Yrs
1 TC ext CJC	721,502	218,025	38,550	11,643	426,862	26,422	94,752	94,171	$1{,}386\times10^6$ h 158 Yrs
2 TC no CJC	721,502	219,685	38,550	11,643	425,202	26,422	94,735	94,150	$1{,}386\times10^6$ h 158 Yrs
2 TC int CJC	721,502	217,325	38,550	11,643	427,352	26,632	94,718	94,134	$1{,}386\times10^6$ h 158 Yrs
2 TC ext CJC	721,502	216,805	38,550	11,643	428,082	26,422	94,765	94,187	$1{,}386\times10^6$ h 158 Yrs

HFT=0, Route 1_H	SIL 2
HFT=1, Route 1_H	SIL 3
Systematic Capability, Route 1_S	SC 3 (SIL 3 Capable)
Subsystem	Type B

The products can be used in safety-related systems that meet the requirements up to and including SIL 3. SIL verification of a safety-related system is the responsibility of the system integrator.

Certificate No. 940/CW/001 was issued by UDT-CERT, Office of Technical Inspection, Szczęśliwicka 34 St., 02-353 Warsaw 10.01.2020.

Warsaw, 16.01.2020

Daniel Samczak
Functional Safety Coordinator

SIL DECLARATION OF CONFORMITY

Document number EN.DZ.LI.24.G.SIL.ID.REV1

Manufacturer: **APLISENS S.A.,**
Morelowa 7 St., 03-192 Warsaw

Declare with full responsibility that:

head-mounted smart temperature transmitters
LI-24G Safety ID: 0004 0006 0003 XXXX XXXX XXXX XXXX XX[1)]

[1)]X in the ID code is manufacturer's indication not related to the certificate

meet the requirements of standards:
PN-EN 61508:2010 Part 1÷7
PN-EN 61511-1:2017-07 + PN-EN 61511-1:2017-07/A1:2018-03
PN-EN 62061:2008 + PN-EN 62061:2008/A1:2013-06 + PN-EN 62061:2008/A2:2016-01

Configuration	λ_{total} FIT	λ_{NE} FIT	λ_{SD} FIT	λ_{SU} FIT	λ_{DD} FIT	λ_{DU} FIT	SFF %	DC %	MTBF
1 RTD 2p	693,502	204,135	38,550	11,643	412,752	26,422	94,601	93,984	$1{,}442\times10^6$ h 164 Yrs
1 RTD 3p	693,502	203,315	38,550	11,643	413,572	26,422	94,610	93,995	$1{,}442\times10^6$ h 164 Yrs
1 RTD 4p	693,502	202,495	38,550	11,643	414,392	26,422	94,619	94,006	$1{,}442\times10^6$ h 164 Yrs
2 RTD 2p	693,502	202,495	38,550	11,643	414,392	26,422	94,619	94,006	$1{,}442\times10^6$ h 164 Yrs
2 RTD 3p	693,502	200,855	38,550	11,643	416,032	26,422	94,637	94,028	$1{,}442\times10^6$ h 164 Yrs
1 TC no CJC	693,502	205,375	38,550	11,643	411,512	26,422	94,587	93,967	$1{,}442\times10^6$ h 164 Yrs
1 TC int CJC	693,502	203,015	38,550	11,643	413,662	26,632	94,570	93,951	$1{,}442\times10^6$ h 164 Yrs
1 TC ext CJC	693,502	202,495	38,550	11,643	414,392	26,422	94,619	94,006	$1{,}442\times10^6$ h 164 Yrs
2 TC no CJC	693,502	204,155	38,550	11,643	412,732	26,422	94,601	93,983	$1{,}442\times10^6$ h 164 Yrs
2 TC int CJC	693,502	201,795	38,550	11,643	414,882	26,632	94,584	93,968	$1{,}442\times10^6$ h 164 Yrs
2 TC ext CJC	693,502	201,275	38,550	11,643	415,612	26,422	94,632	94,023	$1{,}442\times10^6$ h 164 Yrs

HFT=0, Route 1_H	SIL 2
HFT=1, Route 1_H	SIL 3
Systematic Capability, Route 1_S	SC 3 (SIL 3 Capable)
Subsystem	Type B

The products can be used in safety-related systems that meet the requirements up to and including SIL 3. SIL verification of a safety-related system is the responsibility of the system integrator.

Certificate No. 940/CW/001 was issued by UDT-CERT, Office of Technical Inspection, Szczęśliwicka 34 St., 02-353 Warsaw 10.01.2020.

Warsaw, 16.01.2020

Daniel Samczak
Functional Safety Coordinator

Urząd Dozoru Technicznego
UDT-CERT

CERTIFICATE

No. 940/CW/001

Office of Technical Inspection
Product Certification Body UDT-CERT

certifies that

temperature transmitter
LI-24L Safety ID: 0003 0005 0003 XXXX XXXX XXXX XXXX XX[1)]

temperature transmitter
LI-24G Safety ID: 0004 0006 0003 XXXX XXXX XXXX XXXX XX[1)]

[1)] X manufacturer's designation in the ID code, not related to the certificate

manufactured by

APLISENS S.A.
ul. Morelowa 7
03-192 Warszawa

satisfy the requirements of the standards:

PN-EN 61508:2010 parts 1 ÷ 7
PN-EN 61511-1:2017-07 + PN-EN 61511-1:2017-07/A1:2018-03
PN-EN 62061:2008 + PN-EN 62061:2008/A1:2013-06 + PN-EN 62061:2008/A2:2016-01

for safety integrity level

up to and including SIL 3, with a tolerance of hardware HFT=1 according to Route 1_H
up to and including SIL 2, with a tolerance of hardware HFT=0 according to Route 1_H

and satisfy the requirements of systematic integrity

up to and including SC3 according to Route 1_S

Reliability parameters of certified products are presented in the Annex to the Certificate.

The products can be used in safety-related systems that meet the requirements up to and including SIL 3. SIL verification of a safety-related system is the responsibility of the system integrator.

The conditions for issue and validity of the Certificate are specified in the Annex.

Date of issue: **10.01.2020**

Director of Certification and Conformity Assessment Department

Jacek Niemczyk

UDT-CERT, 02-353 WARSZAWA, ul. SZCZĘŚLIWICKA 34

4. DEFINITIONS AND ACRONYMS

SIL – safety integrity level. It is a discreet level of 1 out of 4 possible levels, corresponding to a range of safety integrity values, where safety integrity level 4 is the highest safety integrity level and safety integrity level 1 is the lowest safety integrity level.

SFF – share of safe failures. Percentage of safe failure/defects which cannot cause a system failure. The higher the value, the lower the probability of a dangerous system failure.

DC – diagnostic coverage. Measure of system capability to detect failures. The ratio between detected failure rates and the overall failure rate of all failures in the system.

PFH – probability of dangerous failure per hour.

PFD_{avg} – average probability of failure on demand. Average probability of a dangerous failure of a safety function in the operation mode on demand.

MTBF – Mean Time Between Failures. Describes the operation time between two consecutive component failures. MTBF refers to equipment reliability.

HFT – Hardware Failure Tolerance. Equipment capability to continue to performing the required safety function despite occurring failures.

MTTR – Mean Time To Repair. Average time between a failure occurrence and repair completion. MTTR includes the time necessary to detect a failure, begin and complete a repair.

MRT – expected total repair time (does not include time for fault detection).

FMEDA – Failure Modes Effects and Diagnostics Analysis. Detailed analysis of different emergency modes and equipment diagnostic capabilities.

ALARM_L – diagnostic alarm state in which I_ALARM_L current is lower than 3,600 mA.

FIT – Failure In Time. The value defined as the failure rate (λ) per billion hours.

λ – failure rate. Defines the failure rate, i.e. the number of system failures per time unit.
λ_{SD} – failure rate of safe detectable failures.
λ_{SU} – failure rate of safe non-detectable failures.
λ_{DD} – failure rate of dangerous detectable failures.
λ_{DU} – failure rate of dangerous non-detectable failures.
λ_{NE} – failure rate of failures with no effect.
λ_{total} – failure rate of failures (total of all component failure rates).

5. GENERAL INFORMATION

The safety function of the **LI-24L Safety** and **LI-24G Safety** transmitters is the measurement of temperature with the assumed precision and accuracy. This measurement controls the current proportionally in a 2-wire current loop 4…20 mA.
The standard, intrinsically safe Exi versions of **LI-24L(G) Safety** series transmitters are used for measurement in systems ensuring the **SIL2** safety integrity level in accordance with **PN-EN 61508:2010**.

5.1. Technical parameters

Table 1. Technical parameters of LI-24L(G) Safety transmitters.

Version	Power supply	Diagnostic alarms	
Exi	10 ÷ 30 V DC	Internal diagnostic	low (LO)<3,600 mA
		Critical	low (LO)<<3,600 mA
		External diagnostic PLC	high (HI)>20,820 mA
Standard	10 ÷ 36 V DC	Internal diagnostic	low (LO)<3,600 mA
		Critical	low (LO)<<3,600 mA
		External diagnostic PLC	high (HI)>20,820 mA

Table 2. Operating (ambient) temperatures for LI-24L(G) Safety transmitters.

Ambient temperature		
Product	**Standard version (min; max)**	**Exi version (min; max)**
LI-24L Safety	- 40 ÷ 85 °C	- 40 ÷ 85 °C *)
LI-24G Safety	- 40 ÷ 85 °C	- 40 ÷ 70 °C *)

*) For intrinsically safe versions, due to possible limitations of ATEX standard, the maximum operating temperature for:

- **LI-24L Safety:**
  T4= - 40 ÷ 85 °C;
  T5= - 40 ÷ 55 °C.
- **LI-24G Safety:**
  T5= - 40 ÷ 70 °C;
  T6= - 40 ÷ 50 °C.

6. Description of safety requirements and restrictions

Under the following operating conditions, the safety function is not guaranteed:

– when configuring the transmitter using HART® communication;
– when HART multi-drop is active;
– during simulating states using HART communication;
– during EMC immunity tests;
– when write protect is disabled.

The transmitter configured to operate in a functional safety loop after the necessary settings related to its identification, metrology and alarm modes **must** be set to locked data saving to the transmitter by means of the HART protocol, made via Raport 2 or other software using DD or DTM libraries.
HART® is a registered trademark of FieldComm Group.

The acceptable FMEDA safe measurement error margin of the analog current output for "No Effect" errors is: **2%.**
Maximum time to complete a full diagnostic cycle: **2 minutes**.
Lifetime: **50 years**, determined based on component wear.
The lifetime does not apply to process connections and RTD/TC sensors.

6.1. Alarms

The LI-24L(G) Safety series transmitters are fitted with an alarm system activated when hazardous conditions are detected by internal diagnostics.

The transmitter diagnostics detects the following hazardous conditions:

- failure of FLASH memory and RAM of the CPU microcontroller;
- overflow of CPU microcontroller stack;
- error in transmission with the ADC measuring the process value (failure of the digital signal transmission path through a galvanic barrier);
- too low transmitter power supply voltage;
- exceeding the threshold values of the power supply in the CPU microcontroller circuits;
- exceeding the threshold values of the power supply in the circuits of the ADC transmitter measuring the process value;
- failure of the ratiometric references or their excessive drift;
- failure or excessive drift of the reference voltage sources;
- failure of integrity of the CPU program execution;
- failure of connections between components or in the components of the ADC measurement path, power supplies in the sensor measurement area;
- failure of connections between components or in the components of the D/A and U/I processing path;
- exceeding the permissible limit of 2% between the set point (process) current and the value measured in the 4…20 mA loop;
- exceeding the limit operating temperatures of the ADC transducer measuring the process value;
- failures by short-circuiting or disconnecting any of the temperature sensor(s) connection branches to the transmitter.

Some diagnostics have trigger thresholds that eliminate stochastic events in favour of correlated events. This applies in particular to possible effects of EMC interference on digital transmission in the areas of the SPI bus and in the area of galvanic isolation signal amplifiers.

The transmitter diagnostics shall **not detect** the following:

- temperature measurement errors resulting from failure of a measuring sensor in single or dual sensor configurations, if, despite a sensor failure consisting in a falsification of the measurement value, the electrical continuity of connections to the sensor is maintained;
- excessive vibration or impacts, unless resulting in destruction of internal components or electrical connections causing failures analysed in FMEDA.

Due to the nature of the power supply and the electrical interface of the transmitter, an alarm current level is used for signalling alarm states.
In the diagnostic alarm mode, the transmitter shall issue the nominal current with values: **I_ALARM_L = 3,600 mA – E** where E is assumed in FMEDA, an acceptable 2% safe fault, equivalent to ± 320 μA DC in current loop current. Finally, the rated current set point in the ALARM_L mode should be 3,280 mA.
Transmitter diagnostics does not apply current alarm mode above the range of 20,500 mA. However, a small part of the failures may not be detected by the internal diagnostics and may cause an increase of the process current above 20,500 mA + E, where E is the acceptable 2% safe error level assumed in FMEDA, equivalent to ± 0,320 mA DC in the current loop.
For this reason, when setting up the PLC for working with the transmitter, the current level above 20,820 mA should be considered as Dangerous Detected (detectable dangerous failure).
The current value I_ALARM_L (FAIL SAFE) in normal diagnostic mode is less than 3,600 mA and is nominally **3,280 mA**. In critical alarm mode, the current value I_ALARM_L (FAIL SAFE) is less than **3,600 mA** and is nominally about **0,300 mA**.

Diagnostic alarms are permanently enabled and are not configurable.
In case of critical alarms, the microcontroller immediately transfers control to an infinite loop triggering an independent WDT_SIL watchdog with a time discriminator. Without refreshing, the WDT_SIL will within 2 seconds disconnect the transmitter's main electronics from power supply causing a drop of current below 0,3 mA. This condition will continue until the transmitter is fully disconnected form the power and reconnected.

The causes of critical alarms are:
- error of floating-point mathematical calculations;
- RAM memory failure detection;
- FLASH memory failure detection;
- CPU registry error detection;
- discrepancy of 3 successive current loop current measurements with the setpoint current;
- disruption of the program automaton resulting in exceeding the WDT_SIL refresh time window;
- exceeding the lower threshold of the CPU microcontroller power supply voltage.

Diagnostic alarm states (except critical) can be read via **HART** communication. The Raport 2 software or other software using DD/DTM libraries allows for more accurate identification of the cause of the alarm.

The transmitter is equipped with a LED indicator that indicates the operating status of the unit.
Description of displayed prompts:
- green – correct operating status;
- red – hardware failure;
- flashing red – no or incorrect connection of the RTD/TC sensor, exceeded ambient temperature; excessive drift of reference voltages;
- LED indicator OFF – critical alarm (the transmitter disconnects from power supply).

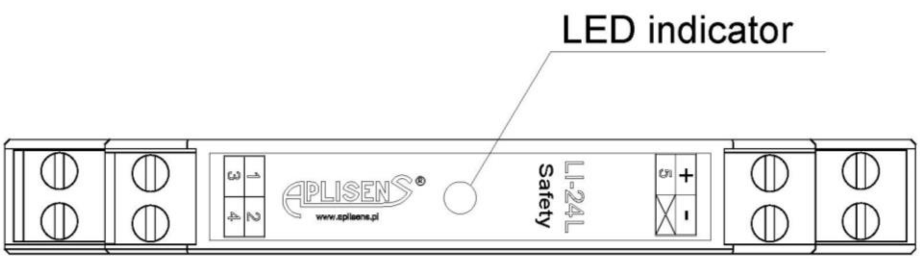

Figure 1. LED indicator in LI-24L Safety transmitter.

6.2. Restrictions

The restrictions on the use of the LI-24L(G) Safety series transmitters in functional safety systems include the following:

- the measuring transmitter **must** be adapted for the application in terms of the ambient operating conditions;
- the permissible operating ranges of the transmitter **must not be exceeded**;
- a faulty transmitter must be replaced **immediately** after a failure is found.

6.3. Notes on cybernetic security

Industrial control systems that have already worked as isolated systems are now based on open platforms, have contact points with an enterprise data communication system and use communications, via public Internet or most often poorly protected networks. Taking into account cyber security after making the necessary transmitter settings related to its identification, metrology and alarm modes, the transmitter interlock must be enabled remote (by HART) write protection against parameter changes.

After configuring and commissioning the functional safety system, use only the analogue current output signal. The responsibility for cybersecurity rests with the system operator who must provide a safe connection between the E/E/PE safety-related system and the plant network. The operator shall establish and maintain any appropriate means of authentication, encryption and installation of any appropriate software to protect the automation system against any security breach, unauthorised access, tampering, intrusion, corruption or data theft.

If, as a result of cyber-attack, the threshold number of unauthorised access attempts to change the password or write protection is exceeded, an alarm will be triggered in the transmitter. Access to the lockout disable function is protected by the 32-bit password (4,3 billion combinations). After 20 unauthorised access attempts, an alarm is triggered until the transmitter software or hardware reset.

Aplisens S.A. and its subsidiaries shall not be liable for any damages and/or loss related to such safety breaches, such as unauthorised access, tampering, intrusion, break-in, data or information leak and/or theft.

7. Repair

No repairs or alterations to the transmitter electronic system are permitted. Failure assessment and repair may only be performed by the APLISENS S.A. service centre. The safety functions cannot be guaranteed in the event of any unauthorised repair.

8. Reliability data

8.1 Failure mode of temperature sensors

Fundamental for optimal safety at the temperature measuring point is the correct design of the electrical thermometer, corresponding to the requirements of the process. The next step is the selection of a temperature transmitter suitable for safety systems, that detects as many fault types as possible of the electrical thermometer and of the transmitter itself.

To determine a temperature measuring point adapted to a safety-related system, consider the following:

- the safe state of the device and the safety function of each item must be determined by the user of the device;
- the required safety integrity level must be determined by the operator of the safety system through a risk assessment;
- the thermometer's operating conditions (process medium, environmental influences) should be sufficiently specified so that the temperature measuring point can be designed optimally in co-operation;
- follow the instructions provided in the documentation of the manufacturer of the temperature sensor used;
- check that the wetted parts are suitable for the measuring medium.

The following failures can occur in an electrical thermometer:

- open circuit – the measuring circuit is interrupted;
- short circuit - the measuring circuit is short-circuited (short circuit of the measuring element);
- drift - due to changes in the resistor material or drift in the thermoelectric voltage.

Depending on the possibility of fault detection in the temperature transducer used, the types of fault intensity coefficients (λ_{SD}, λ_{SU}, λ_{DD}, λ_{DU}) should be determined for various types of temperature sensor defects.

In order to estimate the failure intensities of the whole assembly, i.e. the transducer with a connected sensor, it is necessary to convert with the appropriate input configuration of the transducer with the selected temperature sensor.

Table 3. Detection of sensor failure in temperature transmitters LI-24L Safety, LI-24G Safety.

Failure mode	RTD 2p	RTD 3p	RTD 4p	TC
Open circuit	λ_{DD}	λ_{DD}	λ_{DD}	λ_{DD}
Short circuit	λ_{DD}	λ_{DD}	λ_{DD}	λ_{DU}
Drift	λ_{DU}	λ_{DU}	λ_{DU}	λ_{DU}

RTD – resistance thermometer;
Xp – sensor in X-wire system;
TC – thermocouple.

Types of failure to thermocouples and resistance sensors are given in the literature for various applications and configuration. The failure rates are based on the “worst case” of a thermometer failure and serve as guidance for the design of safety instrumented systems. The failure rates should be used taking into account the operating conditions and the connecting cable between the measuring point and the transmitter. They differ depending on the vibration requirements at the site of operation (low stress/high stress) and the type of connection between the measuring point and temperature transmitter (close connection to the head-mounted transmitter or distance connection with a rail-mounted transmitter).

Table 4. Failure intensity factors for a resistance sensor 2-wire or 3-wire with close connection without a temperature transmitter.

Component use category	The value of the failure intensity factor
Low stress	48,0 FIT
High stress	960,0 FIT

Failure mode	Failure percentage distribution
Open circuit	79,0
Short circuit	3,0
Drift	18,0

Table 5. Failure intensity factors for a resistance sensor 2-wire or 3-wire with distance connection without a temperature transmitter.

Component use category	The value of the failure intensity factor
Low stress	475,0 FIT
High stress	9500,0 FIT

Failure mode	Failure percentage distribution
Open circuit	78,0
Short circuit	2,0
Drift	20,0

Table 6. Failure intensity factors for a resistance sensor 4-wire with close connection without a temperature transmitter.

Component use category	The value of the failure intensity factor
Low stress	50,0 FIT
High stress	1000,0 FIT

Failure mode	Failure percentage distribution
Open circuit	83,0
Short circuit	5,0
Drift	12,0

Table 7. Failure intensity factors for a resistance sensor 4-wire with distance connection without a temperature transmitter.

Component use category	The value of the failure intensity factor
Low stress	500,0 FIT
High stress	10000,0 FIT

Failure mode	Failure percentage distribution
Open circuit	82,0
Short circuit	4,0
Drift	14,0

Table 8. Failure intensity factors for thermocouples with close connection without a temperature transmitter.

Component use category	The value of the failure intensity factor
Low stress	100,0 FIT
High stress	2000,0 FIT

Failure mode	Failure percentage distribution
Open circuit	95,0
Short circuit	4,0
Drift	1,0

Table 9. Failure intensity factors for thermocouples with distance connection without a temperature transmitter.

Component use category	The value of the failure intensity factor
Low stress	1000,0 FIT
High stress	20000,0 FIT

Failure mode	Failure percentage distribution
Open circuit	90,0
Short circuit	5,0
Drift	5,0

Failure intensities given in the tables are based on reliability data from the Electrical & Mechanical Component Reliability Handbook by Exida, Third Edition, Volume 1.

8.2 Reliability data of temperature transmitter

Table 10. Reliability data for LI-24L Safety.

Configuration	λ_{total} FIT	λ_{NE} FIT	λ_{SD} FIT	λ_{SU} FIT	λ_{DD} FIT	λ_{DU} FIT	**SFF** %	**DC** %	**MTBF**
1 RTD 2p	721,502	219,665	38,550	11,643	425,222	26,422	94,735	94,150	$1{,}386\times10^6$ h 158 Yrs
1 RTD 3p	721,502	218,845	38,550	11,643	426,042	26,422	94,744	94,160	$1{,}386\times10^6$ h 158 Yrs
1 RTD 4p	721,502	218,025	38,550	11,643	426,862	26,422	94,752	94,171	$1{,}386\times10^6$ h 158 Yrs
2 RTD 2p	721,502	218,025	38,550	11,643	426,862	26,422	94,752	94,171	$1{,}386\times10^6$ h 158 Yrs
2 RTD 3p	721,502	216,385	38,550	11,643	428,502	26,422	94,769	94,192	$1{,}386\times10^6$ h 158 Yrs
1 TC no CJC	721,502	220,905	38,550	11,643	423,982	26,422	94,722	94,134	$1{,}386\times10^6$ h 158 Yrs
1 TC int CJC	721,502	218,545	38,550	11,643	426,132	26,632	94,705	94,118	$1{,}386\times10^6$ h 158 Yrs
1 TC ext CJC	721,502	218,025	38,550	11,643	426,862	26,422	94,752	94,171	$1{,}386\times10^6$ h 158 Yrs
2 TC no CJC	721,502	219,685	38,550	11,643	425,202	26,422	94,735	94,150	$1{,}386\times10^6$ h 158 Yrs
2 TC int CJC	721,502	217,325	38,550	11,643	427,352	26,632	94,718	94,134	$1{,}386\times10^6$ h 158 Yrs
2 TC ext CJC	721,502	216,805	38,550	11,643	428,082	26,422	94,765	94,187	$1{,}386\times10^6$ h 158 Yrs

Table 11. Intervals of periodic tests for LI-24L Safety.

Configuration	T[Proof]= 1 year	T[Proof]= 2 years	T[Proof]= 5 years	T[Proof]= 10 years
1 RTD 2p	$PFD_{avg} = 1{,}16\times10^{-4}$	$PFD_{avg} = 2{,}31\times10^{-4}$	$PFD_{avg} = 5{,}79\times10^{-4}$	$PFD_{avg} = 1{,}16\times10^{-3}$
1 RTD 3p	$PFD_{avg} = 1{,}16\times10^{-4}$	$PFD_{avg} = 2{,}31\times10^{-4}$	$PFD_{avg} = 5{,}79\times10^{-4}$	$PFD_{avg} = 1{,}16\times10^{-3}$
1 RTD 4p	$PFD_{avg} = 1{,}16\times10^{-4}$	$PFD_{avg} = 2{,}31\times10^{-4}$	$PFD_{avg} = 5{,}79\times10^{-4}$	$PFD_{avg} = 1{,}16\times10^{-3}$
2 RTD 2p	$PFD_{avg} = 1{,}16\times10^{-4}$	$PFD_{avg} = 2{,}31\times10^{-4}$	$PFD_{avg} = 5{,}79\times10^{-4}$	$PFD_{avg} = 1{,}16\times10^{-3}$
2 RTD 3p	$PFD_{avg} = 1{,}16\times10^{-4}$	$PFD_{avg} = 2{,}31\times10^{-4}$	$PFD_{avg} = 5{,}79\times10^{-4}$	$PFD_{avg} = 1{,}16\times10^{-3}$
1 TC no CJC	$PFD_{avg} = 1{,}16\times10^{-4}$	$PFD_{avg} = 2{,}31\times10^{-4}$	$PFD_{avg} = 5{,}79\times10^{-4}$	$PFD_{avg} = 1{,}16\times10^{-3}$
1 TC int CJC	$PFD_{avg} = 1{,}17\times10^{-4}$	$PFD_{avg} = 2{,}33\times10^{-4}$	$PFD_{avg} = 5{,}83\times10^{-4}$	$PFD_{avg} = 1{,}17\times10^{-3}$
1 TC ext CJC	$PFD_{avg} = 1{,}16\times10^{-4}$	$PFD_{avg} = 2{,}31\times10^{-4}$	$PFD_{avg} = 5{,}79\times10^{-4}$	$PFD_{avg} = 1{,}16\times10^{-3}$
2 TC no CJC	$PFD_{avg} = 1{,}16\times10^{-4}$	$PFD_{avg} = 2{,}31\times10^{-4}$	$PFD_{avg} = 5{,}79\times10^{-4}$	$PFD_{avg} = 1{,}16\times10^{-3}$
2 TC int CJC	$PFD_{avg} = 1{,}17\times10^{-4}$	$PFD_{avg} = 2{,}33\times10^{-4}$	$PFD_{avg} = 5{,}83\times10^{-4}$	$PFD_{avg} = 1{,}17\times10^{-3}$
2 TC ext CJC	$PFD_{avg} = 1{,}16\times10^{-4}$	$PFD_{avg} = 2{,}31\times10^{-4}$	$PFD_{avg} = 5{,}79\times10^{-4}$	$PFD_{avg} = 1{,}16\times10^{-3}$

Table 12. Reliability data for LI-24G Safety.

Configuration	λ_{total} FIT	λ_{NE} FIT	λ_{SD} FIT	λ_{SU} FIT	λ_{DD} FIT	λ_{DU} FIT	SFF %	DC %	MTBF
1 RTD 2p	693,502	204,135	38,550	11,643	412,752	26,422	94,601	93,984	$1{,}442\text{x}10^6$ h 164 Yrs
1 RTD 3p	693,502	203,315	38,550	11,643	413,572	26,422	94,610	93,995	$1{,}442\text{x}10^6$ h 164 Yrs
1 RTD 4p	693,502	202,495	38,550	11,643	414,392	26,422	94,619	94,006	$1{,}442\text{x}10^6$ h 164 Yrs
2 RTD 2p	693,502	202,495	38,550	11,643	414,392	26,422	94,619	94,006	$1{,}442\text{x}10^6$ h 164 Yrs
2 RTD 3p	693,502	200,855	38,550	11,643	416,032	26,422	94,637	94,028	$1{,}442\text{x}10^6$ h 164 Yrs
1 TC no CJC	693,502	205,375	38,550	11,643	411,512	26,422	94,587	93,967	$1{,}442\text{x}10^6$ h 164 Yrs
1 TC int CJC	693,502	203,015	38,550	11,643	413,662	26,632	94,570	93,951	$1{,}442\text{x}10^6$ h 164 Yrs
1 TC ext CJC	693,502	202,495	38,550	11,643	414,392	26,422	94,619	94,006	$1{,}442\text{x}10^6$ h 164 Yrs
2 TC no CJC	693,502	204,155	38,550	11,643	412,732	26,422	94,601	93,983	$1{,}442\text{x}10^6$ h 164 Yrs
2 TC int CJC	693,502	201,795	38,550	11,643	414,882	26,632	94,584	93,968	$1{,}442\text{x}10^6$ h 164 Yrs
2 TC ext CJC	693,502	201,275	38,550	11,643	415,612	26,422	94,632	94,023	$1{,}442\text{x}10^6$ h 164 Yrs

Table 13. Intervals of periodic tests for LI-24G Safety.

Configuration	T[Proof]= 1 year	T[Proof]= 2 years	T[Proof]= 5 years	T[Proof]= 10 years
1 RTD 2p	$PFD_{avg} = 1{,}16×10^{-4}$	$PFD_{avg} = 2{,}31×10^{-4}$	$PFD_{avg} = 5{,}79×10^{-4}$	$PFD_{avg} = 1{,}16×10^{-3}$
1 RTD 3p	$PFD_{avg} = 1{,}16×10^{-4}$	$PFD_{avg} = 2{,}31×10^{-4}$	$PFD_{avg} = 5{,}79×10^{-4}$	$PFD_{avg} = 1{,}16×10^{-3}$
1 RTD 4p	$PFD_{avg} = 1{,}16×10^{-4}$	$PFD_{avg} = 2{,}31×10^{-4}$	$PFD_{avg} = 5{,}79×10^{-4}$	$PFD_{avg} = 1{,}16×10^{-3}$
2 RTD 2p	$PFD_{avg} = 1{,}16×10^{-4}$	$PFD_{avg} = 2{,}31×10^{-4}$	$PFD_{avg} = 5{,}79×10^{-4}$	$PFD_{avg} = 1{,}16×10^{-3}$
2 RTD 3p	$PFD_{avg} = 1{,}16×10^{-4}$	$PFD_{avg} = 2{,}31×10^{-4}$	$PFD_{avg} = 5{,}79×10^{-4}$	$PFD_{avg} = 1{,}16×10^{-3}$
1 TC no CJC	$PFD_{avg} = 1{,}16×10^{-4}$	$PFD_{avg} = 2{,}31×10^{-4}$	$PFD_{avg} = 5{,}79×10^{-4}$	$PFD_{avg} = 1{,}16×10^{-3}$
1 TC int CJC	$PFD_{avg} = 1{,}17×10^{-4}$	$PFD_{avg} = 2{,}33×10^{-4}$	$PFD_{avg} = 5{,}83×10^{-4}$	$PFD_{avg} = 1{,}17×10^{-3}$
1 TC ext CJC	$PFD_{avg} = 1{,}16×10^{-4}$	$PFD_{avg} = 2{,}31×10^{-4}$	$PFD_{avg} = 5{,}79×10^{-4}$	$PFD_{avg} = 1{,}16×10^{-3}$
2 TC no CJC	$PFD_{avg} = 1{,}16×10^{-4}$	$PFD_{avg} = 2{,}31×10^{-4}$	$PFD_{avg} = 5{,}79×10^{-4}$	$PFD_{avg} = 1{,}16×10^{-3}$
2 TC int CJC	$PFD_{avg} = 1{,}17×10^{-4}$	$PFD_{avg} = 2{,}33×10^{-4}$	$PFD_{avg} = 5{,}83×10^{-4}$	$PFD_{avg} = 1{,}17×10^{-3}$
2 TC ext CJC	$PFD_{avg} = 1{,}16×10^{-4}$	$PFD_{avg} = 2{,}31×10^{-4}$	$PFD_{avg} = 5{,}79×10^{-4}$	$PFD_{avg} = 1{,}16×10^{-3}$

Systematic Capability	SC 3 (SIL 3 Capable)
Random Capability	Type B Element SIL2@HFT=0; SIL3@HFT=1; Route 1_H

PFH = λ_{DU}.
MTTR = MRT = 8 h.
For the above products, the manufacturer recommends the following intervals of periodic tests: **T[Proof] = 1 year.**

9. History of revisions

Revision No.	Document revision	Date	Description of changes
-	01.A.001	12.2019	First version developed by KBF, DR, DKD.
1	01.A.002	01.2020	Declarations added, certificate, reliability data for temperature sensors, developed by KBF.
2	01.A.003	07.2020	Editorial changes. Developed by DBFD.

APPENDIX A. Proof Tests

It is recommended to carry out the safety function tests (Proof Tests) allowing to detect 99% of possible non-diagnosable dangerous transmitter failures.

The manufacturer recommends the interval of periodic tests **T[Proof] = 1 year.**

The Proof Test is performed using the **RAPORT 2** software with the **SIL PROOF TEST** plugin, developed by APLISENS S.A.

List of Proof Test steps:

1. Configure the PLC operating in the safety loop to a mode enabling to skip measurements and alarms from the transmitter used in the test.

2. Check the physical condition of the transmitter housing and replace the hardened or damaged gaskets and glands causing leaks of the housing (applies to LI-24G Safety).

3. Check the condition of electrical connections (reliability of wire connections to terminals).

4. Run **Raport 2** software developed by APLISENS S.A. on a WINDOWS® PC. Connect a HART modem type HART/USB manufactured by APLISENS S.A. or any other BELL 202 compatible modem to the computer. Connect the power supply, modem and ammeter "**A**" to the power loop of the tested transmitter in accordance with the diagram in **Fig. 1**. Connect a substitute temperature sensor to the transmitter measuring terminals according to the transmitter configuration. Supply the transmitter with a 15,00 V DC voltage measured at the power supply unit terminals.

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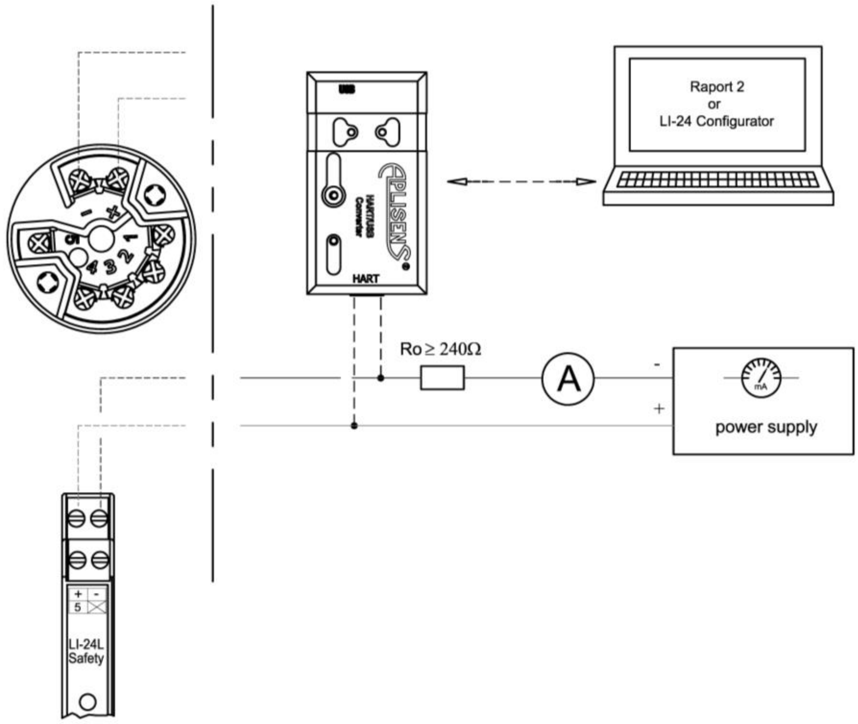


Fig. 1. Diagram of transmitter connection to the current loop for testing.

Identify the transmitter and open the "**SIL Proof Test**" tab. Remove software write protection to the transmitter using a HART command. For this purpose, select the "**Write lock**" in the "**SIL Proof Test**" tab. The test wizard will be launched. Follow the instructions of the wizard which in the next steps will ask about operator's intentions and perform the necessary actions.

5. The purpose of the test is to validate the operation of the process current controller in the transmitter and to validate the current loop diagnostic system in the 4…20 mA loop. To perform the current loop analog output tests, select the "**SIL Proof Test**" tab and the "**Analog Output Test**" menu option. The test wizard will be launched. Follow the instructions of the wizard, which will carry out the tests of the digital/analog converter, the current controller, and the current loop current control circuit tests. The wizard will instruct to:

5.1. Supply the transmitter with a 15,00 V DC voltage measured at the power supply unit terminals. Using a HART command, the transmitter current output is set to 20,820 mA corresponding to the maximum safe transmitter current. Using a reference DC milliammeter "**A**" of accuracy class ≤ 0,025 and internal resistance of ≤ 10 Ω connected in the current loop, read the current flowing in the line. This test, in addition to checking the alarm current value, detects any problems related to the minimum supply voltage of the transmitter's power supply, which may be caused by voltage drops on the power line resistance or the power source resistance.

5.2. When the current output is set to 20,820 mA, the test wizard reads the **PVIret** parameter. The permissible deviation of the **PVIret** parameter is ± 0,032 mA.

5.3. Using a HART command, the transmitter current output is set to 12,000 mA. Using a reference DC milliammeter "**A**" of accuracy class ≤ 0,025 connected in the current loop, read the current flowing in the line. This test detects possible problems in the digital/analog processing circuit (e.g. due to failure of the internal component).

5.4. Using a HART command, the transmitter current output is set to 3,280 mA corresponding to the I_ALARM_L alarm current (minus the permissible error of 2%, i.e. 0,320 mA). Using a reference DC milliammeter "**A**" of accuracy class ≤ 0,025 connected in the current loop, read the current flowing in the line. This test detects any problems related to excessive idle current drawn by the transmitter (e.g. due to an internal component failure).

If the results of the measurements do not meet the assumed parameters, the test wizard recommends performing a calibration procedure for the transmitter analogue output.

If, when the calibration procedure has been performed correctly, the transmitter measurement continues to show a current value deviating from the expected value (taking into account the permissible deviation as stated in the user's manual), the transmitter must be returned immediately to the manufacturer for repair.

6. Process temperature measurement tests.

The purpose of the test is to validate the accuracy of the temperature process variable measurement by simulating an electrical value at the temperature transmitter measurement input. Check the process temperature measurement function for the range and configuration used in the process safety loop, using a temperature calibrator of the required accuracy class, properly connected to the configured measuring terminals of the temperature transmitter. For this purpose, from the "**SIL Proof Test**" tab, select the "**Temperature measurement test**" option. The test wizard will be launched. Follow the instructions of the wizard, which will carry out the temperature tests in the next steps. The transmitter will start the test from reading the input configuration, sensor type, temperature measurement range. If the measured current value in the test items **6.1, 6.2** or **6.3** deviates from the expected values (considering the permissible error), a 2-point temperature calibration procedure shall be performed. The calibration procedure shall be performed with a temperature calibrator of the required accuracy class, connected to the properly configured temperature transmitter measuring terminals. After the calibration, retest by performing the steps of section **6**.

The wizard will instruct to:

6.1. Supply the transmitter with a 15,00 V DC voltage measured at the power supply unit terminals. Using the temperature calibrator, apply a reference signal to the transmitter corresponding to 4 mA (0% of the set temperature range) and with the milliammeter "**A**" of accuracy class ≤ 0,025 and internal resistance ≤ 10 Ω, perform current measurement in the current loop.

6.2. Using the temperature calibrator, apply a reference signal to the transmitter corresponding to 12 mA (50% of the set temperature range) and with the milliammeter “**A**” of accuracy class ≤ 0,025 and internal resistance ≤ 10 Ω, perform current measurement in the current loop.

6.3. Using the temperature calibrator, apply a reference signal to the transmitter corresponding to 20 mA (100% of the set temperature range) and with the milliammeter “**A**” of accuracy class ≤ 0,025 and internal resistance ≤ 10 Ω, perform current measurement in the current loop.

If, despite the 2-point temperature calibration performed, the measured current value in items **6.1**, **6.2** or **6.3** still deviates from the expected value (taking into account the permissible deviation as stated in the user’s manual), **the test is not completed successfully, and the transmitter <u>must</u> be returned to the manufacturer for repair**.

7. Tests for measurement of Cold Junction Compensating (CJC) and ambient temperature.

7.1. Short-circuit the transmitter measuring terminals marked ①, ②, ③. Supply the transmitter with a 15,00 V DC voltage measured at the power supply unit terminals. The purpose of the test is to validate the ambient temperature measurement carried out by the transmitter based on the temperature measurement carried out by the internal ADC converter sensor, and to validate the internal Cold Junction Compensating (CJC) temperature measurement sensor. For this purpose, after stabilising thermal conditions at a temperature of 15 – 25 °C, measure the temperature of the transmitter body with a reference electronic thermometer of at least “B” accuracy class. The “stable thermal conditions” are understood as ensuring a relatively stable and uniform temperature of the transmitter body.

7.2. On the “**SIL Proof Test**” tab, select the “**Environment tests**” option. The test wizard will be launched. Follow the instructions of the wizard, which will carry out the tests in the next steps. The software will properly configure the transmitter for test and read the 1st, 2nd, 3rd and 4th process variables (PV, SV, TV, FV). They correspond successively to the process temperature (PV), the primary sensor temperature (SV), the secondary sensor temperature (TV) and the ADC converter temperature (FV). After completing the test, the wizard will restore the previous configuration of the transmitter.

If, as a result of correctly performed test procedure, the SV, TV, FV temperature values deviate by more than 5°C from the temperature measured using the reference electronic thermometer, **the transmitter <u>must</u> be immediately returned to the manufacturer for repair**.

8. Diagnostics tests for an interruption in the sensor circuit.

8.1. The purpose of the test is to check correct operation of diagnostics of an interruption in the galvanic connection to the temperature measurement sensor. Depending on the temperature sensor configuration used in the measurement process, substitute sensors simulating field sensors shall be connected to the respective transmitter measuring terminals. Supply the transmitter with a 15,00 V DC voltage measured at the power supply unit terminals. Follow the instructions of the wizard, which in the following steps will indicate an interruption in the connection between the sensor and the specified measuring terminal. The result of an interruption should be an alarm current of nominally 3,280 mA, and a red LED flashing status indicator.

If, with a correctly performed test procedure, the transmitter fails to behave as described in the test wizard, **it <u>must</u> be immediately returned to the manufacturer for repair.**

9. Alarm module tests.

9.1. The purpose of the test is to check the operation of the alarm module. On the "**SIL Proof Test**" tab, select the "**Alarm modules test**" option. Depending on the temperature sensor configuration used in the measurement process, substitute sensors simulating field sensors shall be connected to the respective transmitter measuring terminals. Supply the transmitter with a 15,00 V DC voltage measured at the power supply unit terminals. Follow the instructions of the wizard, which will carry out the primary and backup alarm modules tests in the next steps. The result of the test should be an alarm current of nominally 3,280 mA, and a permanently lit red LED status indicator, or in the case of a critical alarm, an alarm current of approximately 0,300 mA.

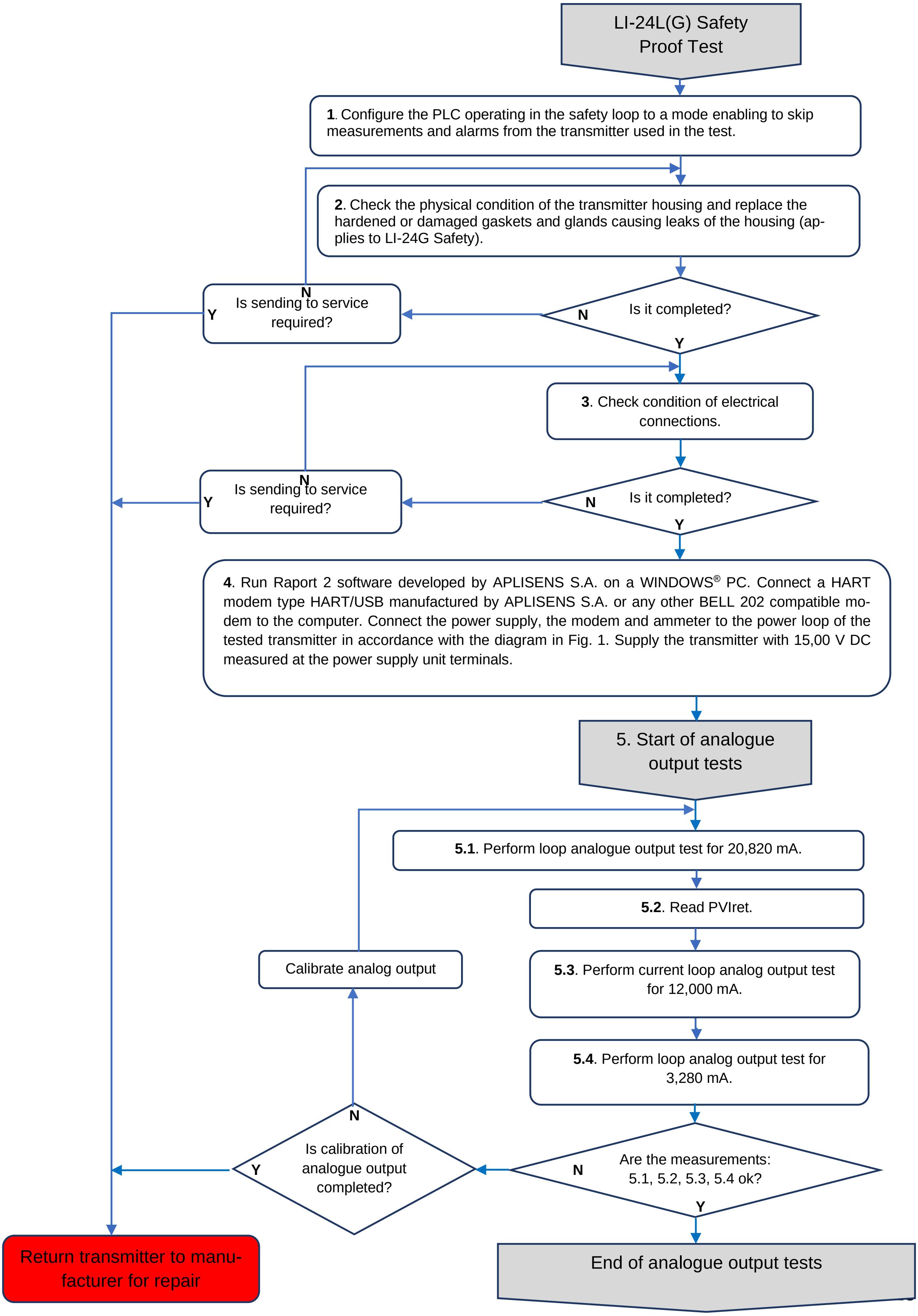
If, with a correctly performed test procedure, the transmitter fails to behave as described in the test wizard, **it <u>must</u> be immediately returned to the manufacturer for repair.**

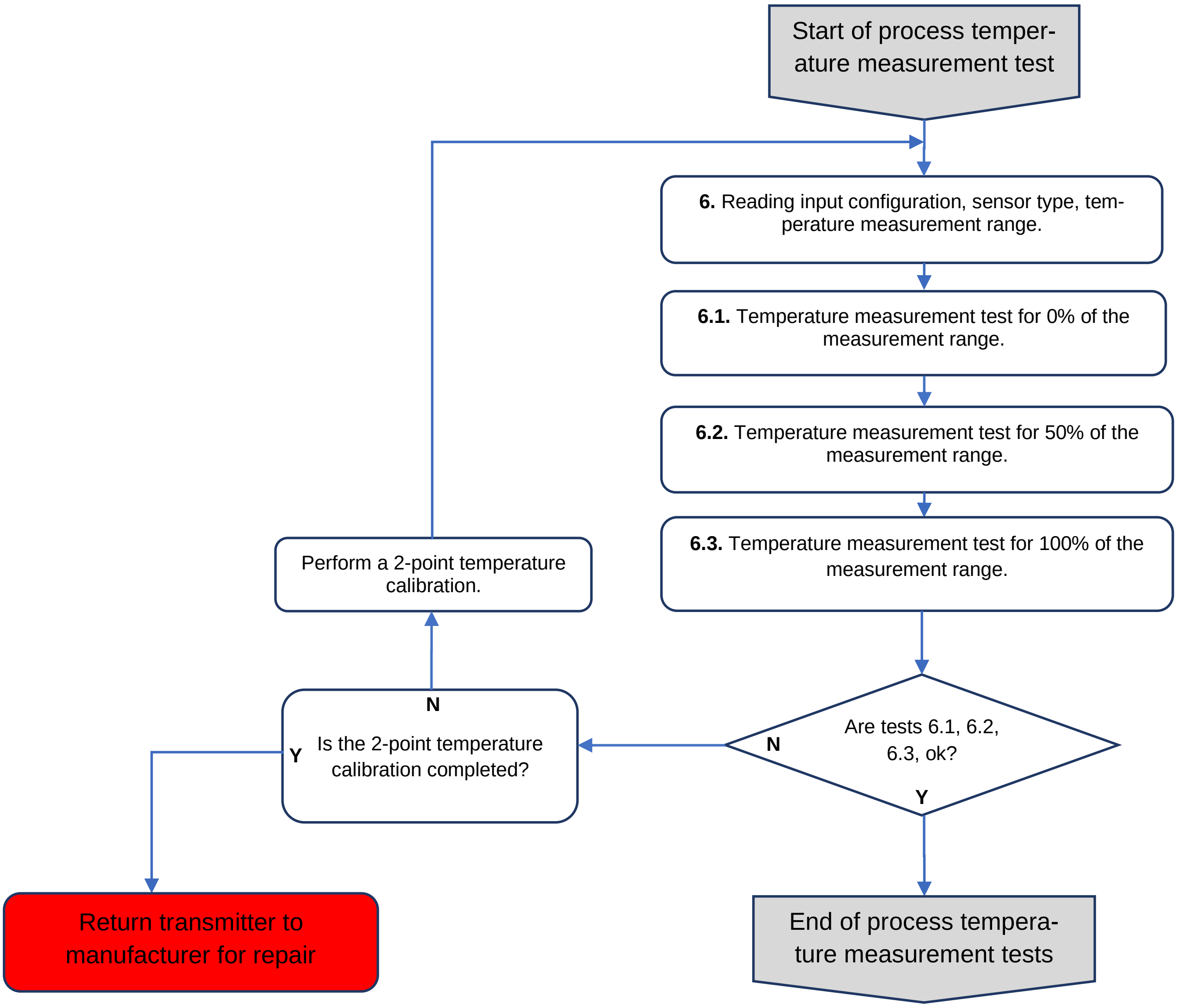
10. Set the software write protection to the transmitter using a **HART** command (Raport 2 software developed by APLISENS S.A.). For this purpose, select the "**Write lock**" in the "**SIL Proof Test**" tab. The test wizard will be launched. Follow the instruction of the wizard which in the next steps will ask about operator's intentions and perform the necessary actions. After successful test completion, the test wizard will generate a test report and set the transmitter to the stand-by mode for connection to the functional safety loop.

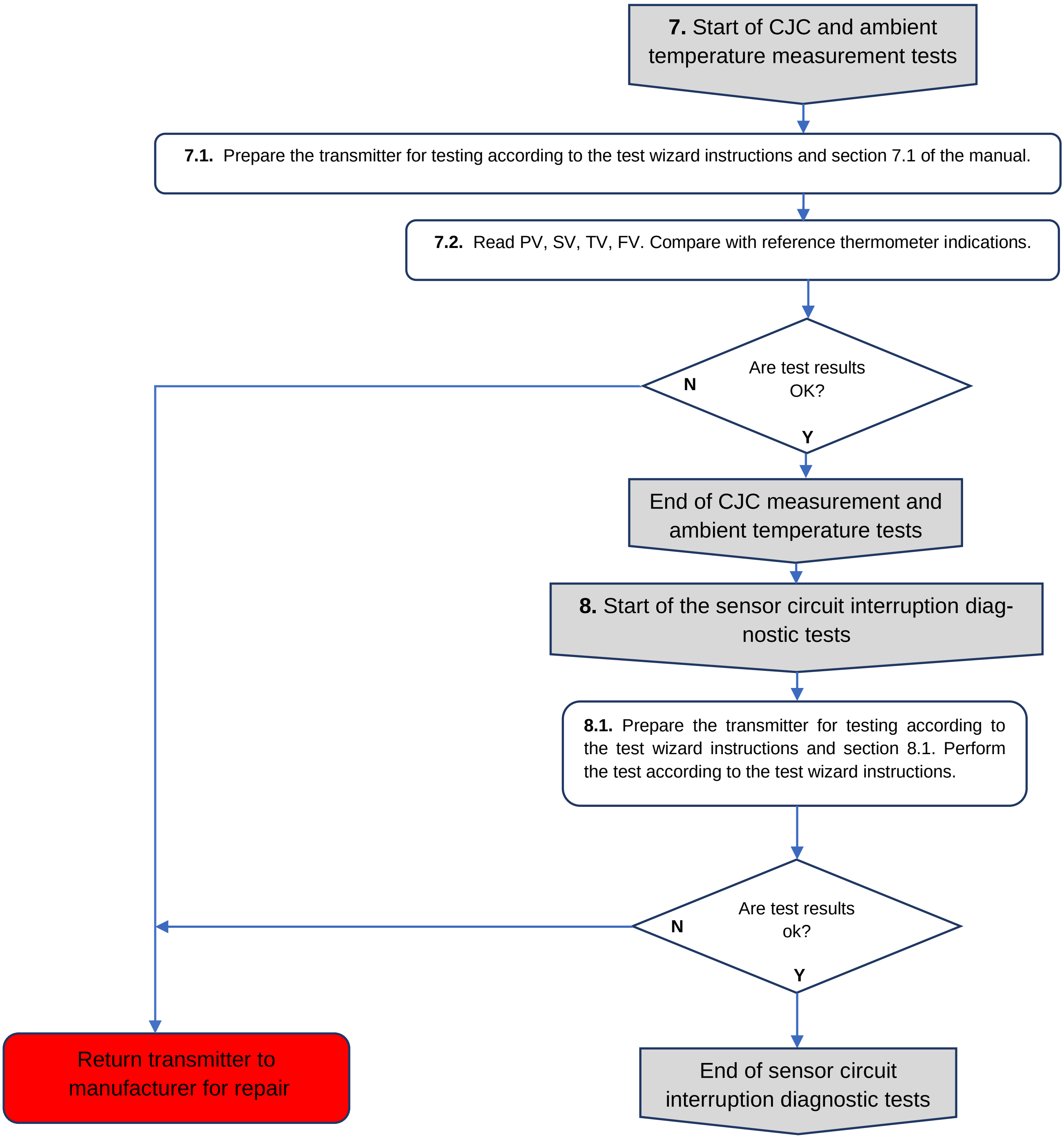
11. Install the transmitter and connect the sensors to it as intended. Configure the PLC operating in the safety loop in a mode enabling to read measurements and alarms from the transmitter used in the test. <u>Record and archive the test results</u>.

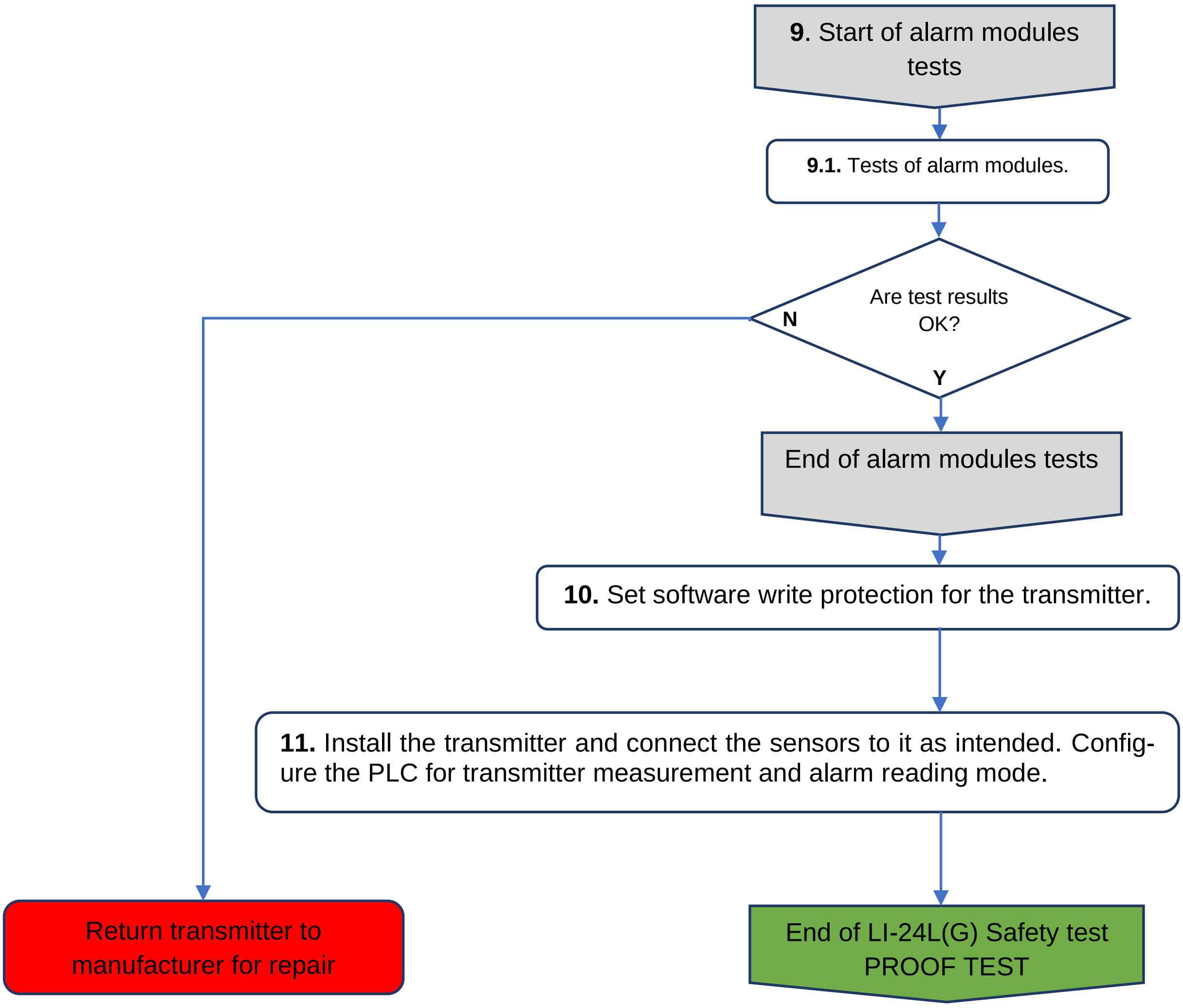
The checklist for performing the Proof Test is available in the **Proof Test** software.

APPENDIX B. The Proof test block diagram.




Start of process temperature measurement test
6. Reading input configuration, sensor type, temperature measurement range.
6.1. Temperature measurement test for 0% of the measurement range.
6.2. Temperature measurement test for 50% of the measurement range.
6.3. Temperature measurement test for 100% of the measurement range.
Perform a 2-point temperature calibration.
Are tests 6.1, 6.2, 6.3, ok?
N
Y
Is the 2-point temperature calibration completed?
N
Y
Return transmitter to manufacturer for repair
End of process temperature measurement tests


7. Start of CJC and ambient temperature measurement tests
7.1. Prepare the transmitter for testing according to the test wizard instructions and section 7.1 of the manual.
7.2. Read PV, SV, TV, FV. Compare with reference thermometer indications.
Are test results OK?
N
Y
End of CJC measurement and ambient temperature tests
8. Start of the sensor circuit interruption diag-nostic tests
8.1. Prepare the transmitter for testing according to the test wizard instructions and section 8.1. Perform the test according to the test wizard instructions.
Are test results ok?
N
Y
Return transmitter to manufacturer for repair
End of sensor circuit interruption diagnostic tests


9. Start of alarm modules tests
9.1. Tests of alarm modules.
Are test results OK?
N
Y
End of alarm modules tests
10. Set software write protection for the transmitter.
11. Install the transmitter and connect the sensors to it as intended. Configure the PLC for transmitter measurement and alarm reading mode.
Return transmitter to manufacturer for repair
End of LI-24L(G) Safety test PROOF TEST