



PROTIUM-1000

FUEL CELL SYSTEM

USER GUIDE

SAFETY, HANDLING & SUPPORT

WARNING:

Failure to follow these safety instructions could result in fire, electric shock, or other injuries, or damage to PROTIUM-1000 Fuel Cell System (PROTIUM-1000) or other property. Read all the safety information below before using PROTIUM-1000.

Handling Handle PROTIUM-1000 with care. It is made of thin sheet metal, graphite, and plastic and has sensitive electrochemical membrane and components inside. PROTIUM-1000 is not designed for extreme conditions, rough handling, vibration, shock or drop. Keep PROTIUM-1000 away from heat, flame, strong sunlight, water, dust, soil or mud. Do not use a damaged PROTIUM-1000.

Repairing PROTIUM-1000 is assembled under high compression. Do not disassemble or tamper with PROTIUM-1000. Do not troubleshoot, repair or replace any component by yourself.

Hydrogen Use only high purity (99.999%) dry Hydrogen gas with PROTIUM-1000. Hydrogen is a colorless, odorless and highly flammable gas. It is non-toxic but can cause asphyxiation. Follow all local rules and regulations for safe handling, storage and usage of Hydrogen gas. Do not smoke when operating PROTIUM-1000.

Ventilation Operate PROTIUM-1000 in a well ventilated environment. Fresh air intake for the fuel cell oxidant blower, cooling air entry from the front of the protective mask, and hot air exit from the cooling fans shall not be obstructed or restricted.

Purging PROTIUM-1000 periodically flushes its anode during operation, releasing Hydrogen gas and water from the Hydrogen gas outlet. Do not block the Hydrogen gas outlet. Do not bring flame or electric spark close to the Hydrogen gas outlet. It is advisable to attach a longer gas tubing to the Hydrogen gas outlet connector and safely guide the purge exhaust far away from the fuel cell.

CAUTION: *Always put the Hydrogen gas outlet tubing behind the cooling fan and never in front of the fuel cell stack or oxidant blower inlet. Purged Hydrogen mixed with air intake into the fuel cell's cathode channels may cause fire and irreversible damage to the fuel cell.*

Connectors, ports and buttons Never force a connector into a port or apply excessive pressure to a button. If the connector and port do not join with reasonable ease, they probably do not match. Check for obstructions and ensure that the connector matches the correct port.

Disposal and recycling As PROTIUM-1000 contains electronic components, it must be disposed of separately from household waste. When PROTIUM-1000 reaches its end of life, follow local laws and regulations for proper disposal and recycling options.

High-consequence activities PROTIUM-1000 is a customized system with pending safety tests and certifications. It is not intended for use where the failure of the system could lead to death, personal injury or severe environmental damage.

Disclaimer Every effort has been made to ensure that the information in this manual is accurate. This manual serves to adequately recommend safe operating procedures, but shall not be treated as comprehensive. Do not use PROTIUM-1000 in any other way than the one recommended in this manual. Spectronik reserves the right to change system specifications, appearance or discontinue the product at any time.

Warranty Spectronik warrants the included hardware product and accessories against defects in materials and workmanship for the first 30 days after delivery. Spectronik does not warrant against normal wear and tear, nor damage caused by accident or abuse.

To obtain service, contact support@spectronik.com

1 OVERVIEW

1.1 PROTIUM-1000 SYSTEM OVERVIEW

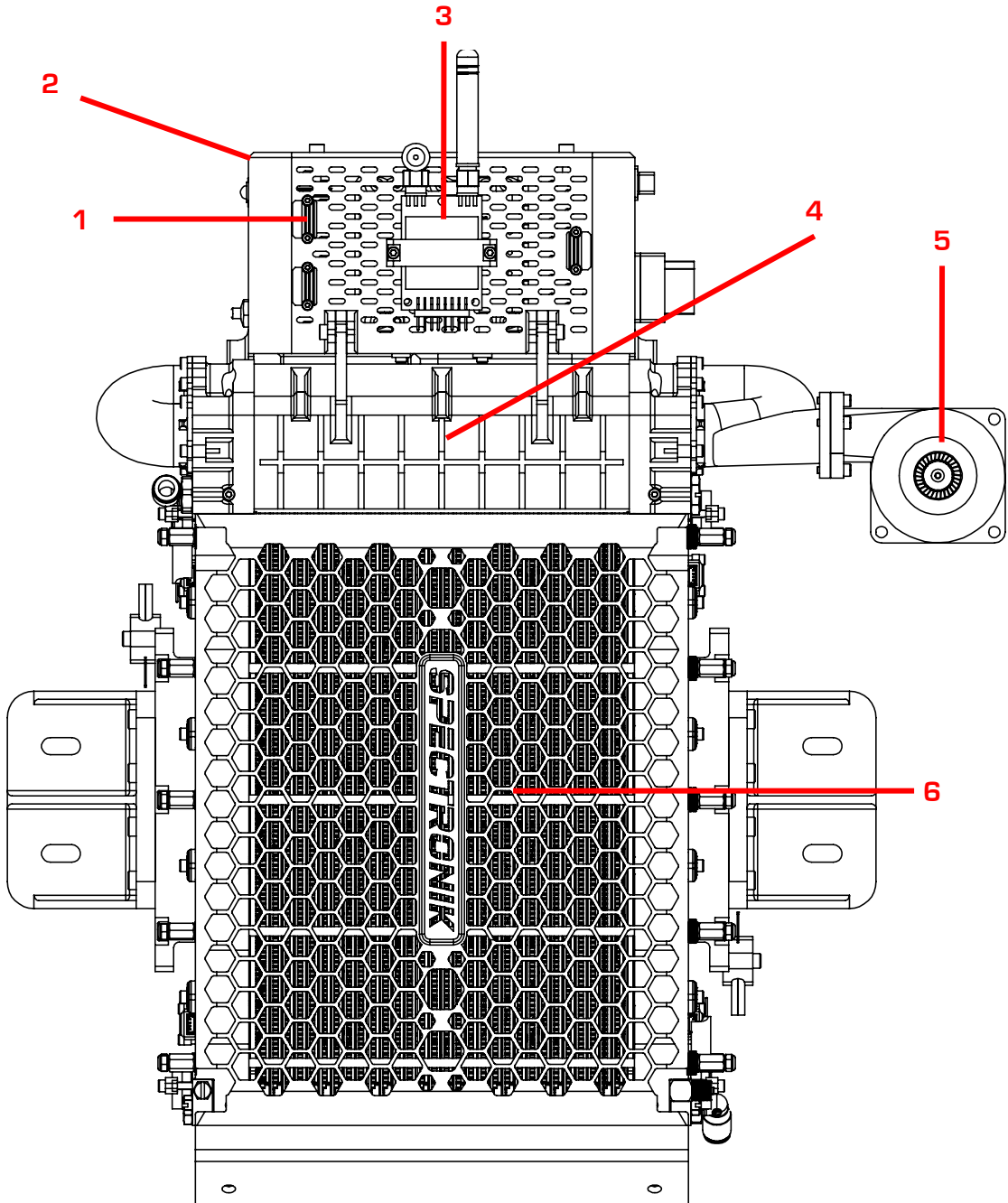


Figure 1.1.1 Front view of PROTIUM-1000

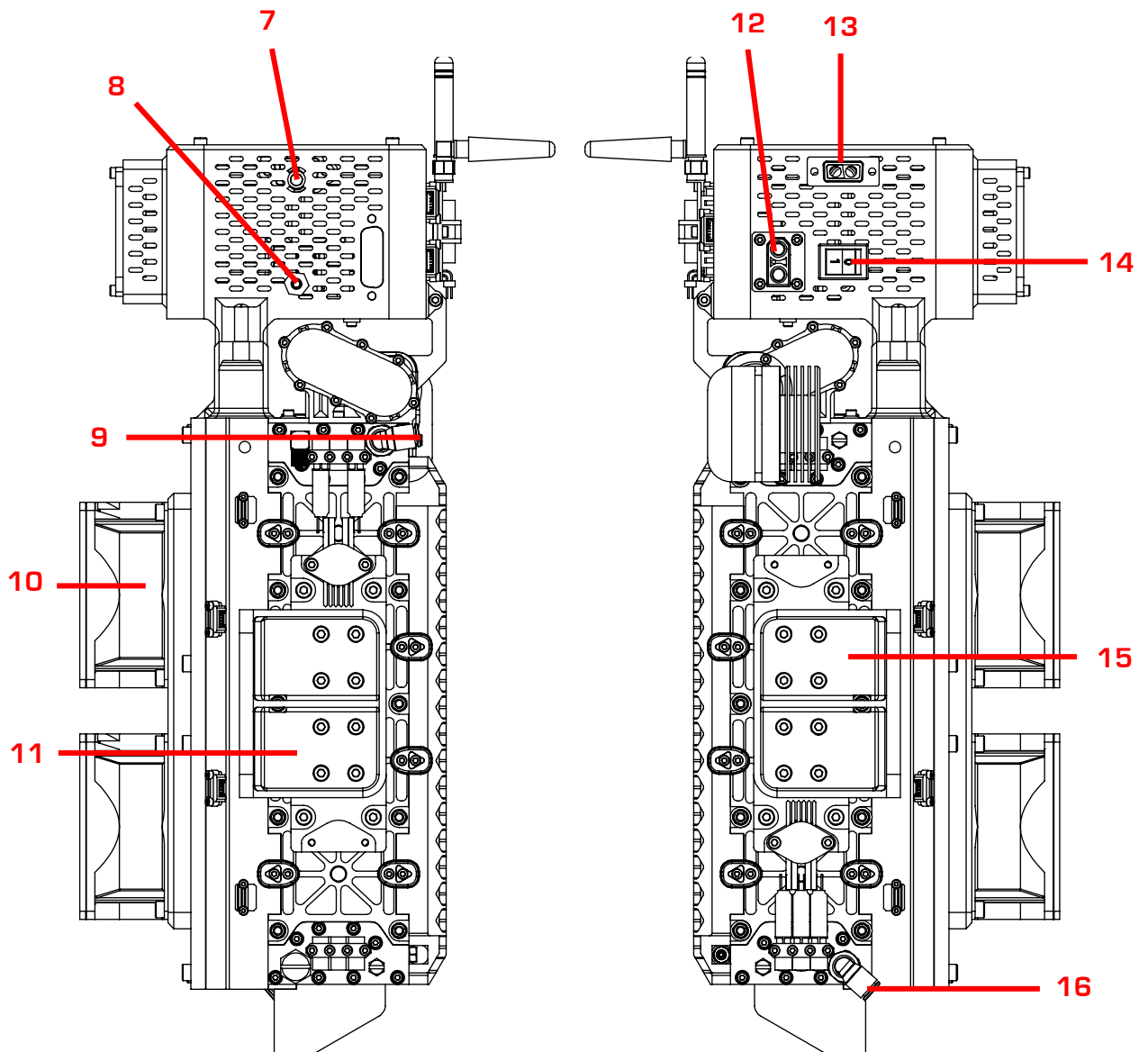
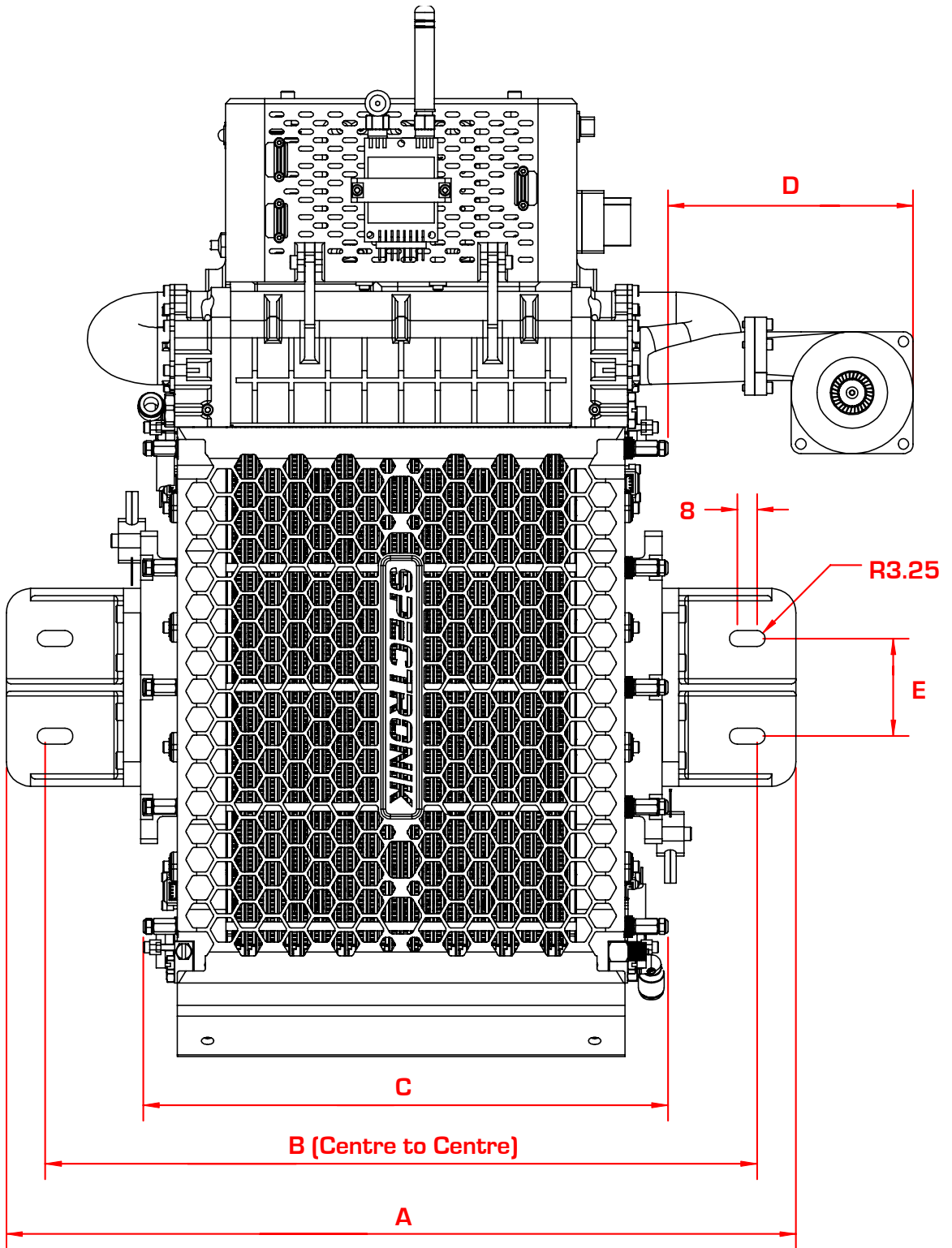


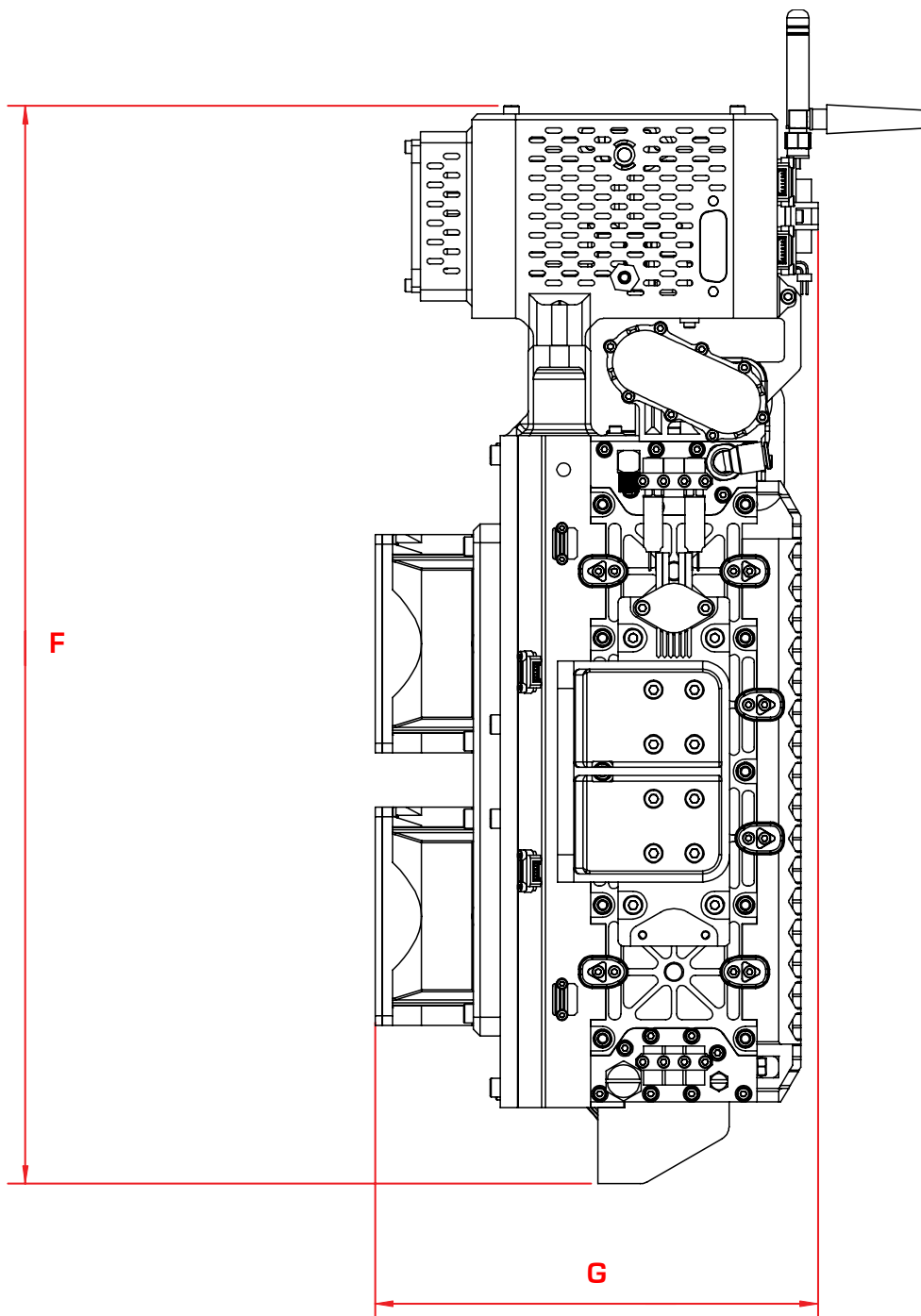
Figure 1.1.2 Bottom and Top views of PROTIUM-1000

ITEM DESCRIPTION

- | | | | |
|----|---------------------------------|-----|-------------------------------------|
| 1. | Programming port | 9. | H ₂ gas outlet connector |
| 2. | Fuel cell electronic controller | 10. | Cooling fan x2 |
| 3. | Radio telemetry transmitter | 11. | User mounting plate (Bottom) |
| 4. | Oxidant flow manifold | 12. | Load power connector (XT-90 female) |
| 5. | Oxidant blower | 13. | External power supply receptacle |
| 6. | Protective mask | 14. | Balance-of-plant (BOP) switch |
| 7. | Status LED | 15. | User mounting plate (Top) |
| 8. | ON/OFF push button | 16. | H ₂ gas inlet connector |

1.2 MECHANICAL DIMENSION





All dimensions in mm

A	323.60	E	40.00
B	283.60	F	395.50
C	215.00	G	164.50
D	100.50		

1.3 Mounting orientation and air clearance

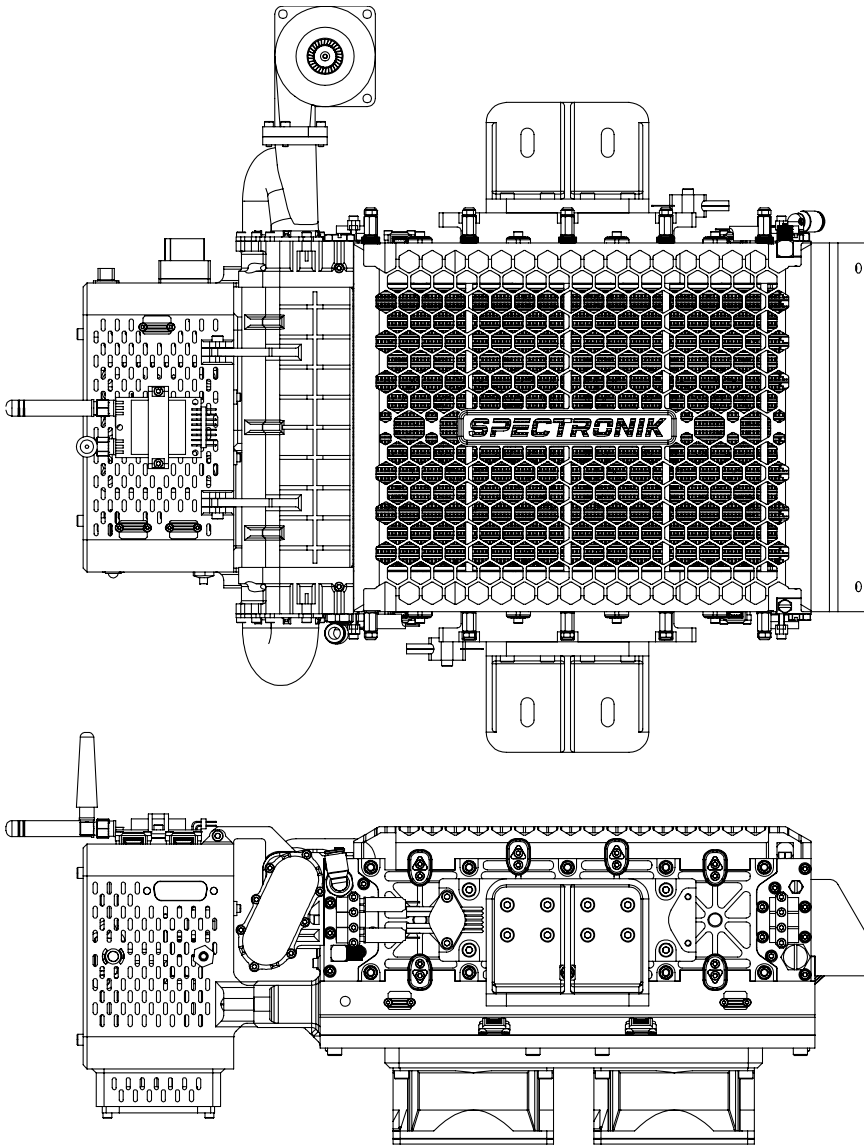


Figure 1.3.1 Recommended configuration #1 (Top) and #2 (Bottom)

PROTIUM-1000 **cannot** be mounted in any orientation due to internal routings of the gas streams within the fuel cell stack.

The fuel inlet must always be higher than the fuel outlet. The stack should also be level to ensure water does not get trapped in the Cathode channels, obstructing the oxidant flow and causing potential performance drop and cell damage.

Mount PROTIUM-1000 in one of the two recommended configurations above.

For optimal oxidant and cooling airflows, it is also recommended that there is **at least 15cm unobstructed clearance in front of the protective mask and oxidant blower inlet, and 30cm unobstructed clearance behind the cooling fans' outlet.**

2 SPECIFICATIONS

2.1 PROTIUM-1000 TECHNICAL DATA SHEET

Fuel Cell	
Type	PEM
No. of cells	30
Architecture	Closed cathode
Coolant	Air cooled
Rated/gross power	1000/1200W
Rated/gross current	55.5/66.6A
Voltage output	18-27VDC
Start-up time	30s
Operating ambient temperature	[-10,45]°C
Operating altitude without power derating	1500m AGL
System weight	4,800g
Max dimension	396 x 165 x 324mm
Fuel Supply	
Hydrogen gas	Dry, 99.999% purity
Delivery pressure	0.7bar (10 psig)
Fuel consumption @ rated power	12.5L/min
Gas tubing	PU, 8 x 5.5
Supply & purge control	Solenoid valves with integrated pressure sensor
Stack leakage checks	Automated via integrated pressure sensors
Electronic Controller	
Processor board	FEATHER V1.2
External power supply requirement	15-90V, 150W max
Weight (including casing)	680g
Output connector	XT-90
Warning & protections	Low voltage, high/low temperature, high/low pressure, low battery, stack leakage
Communication	868MHz ultra long range radio modem
Data acquisition (DAQ) software GUI	PC/Android app
Remote control	Fan speed, blower speed, manual purge, remote on-off

2.2 VI CURVE

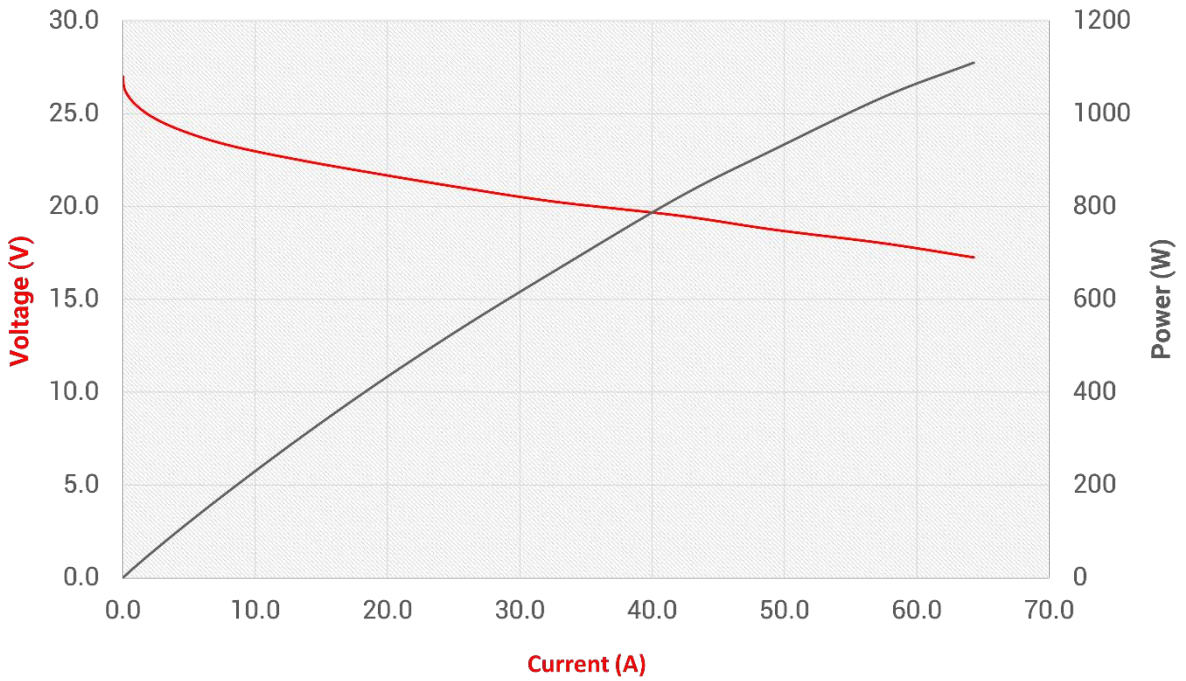
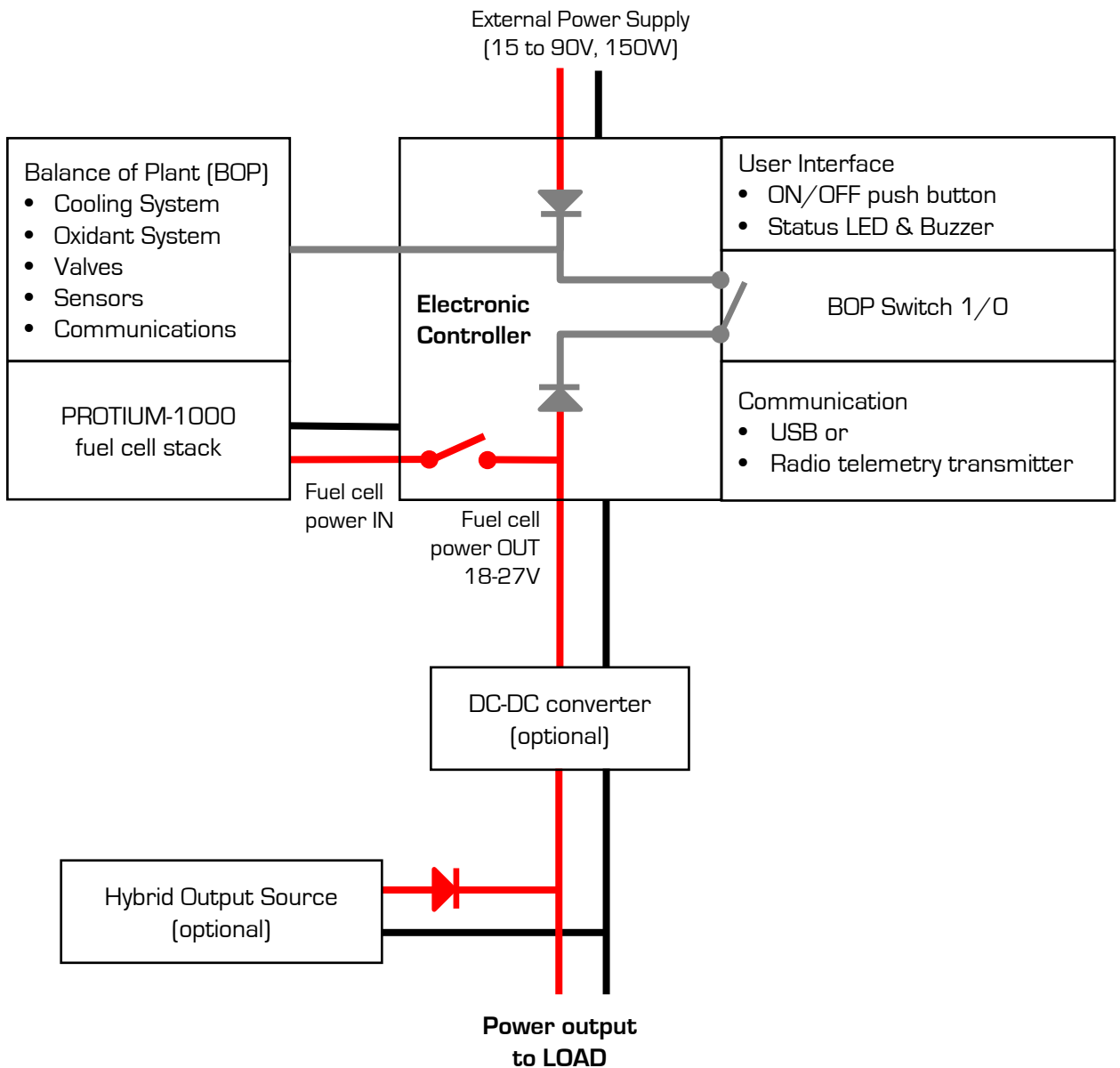


Figure 2.2.1 Nominal polarization curve for a fully conditioned PROTIUM-1000 at its Beginning-of-Life (BOL).

TEST CONDITIONS

- Ambient temperature: 24°C
- Relative humidity: 60%
- H₂ supply pressure: 10psig
- Dead-ended operation
- Balance-of-plant (BOP) powered by fuel cell
- T_{cell} at 1000W: 66°C

2.3 SYSTEM BLOCK DIAGRAM



NOTE

1. An external power supply is required to initially turn on the electronic controller.
2. By default, the *BOP Switch* is set to 1. When the system enters "Running Phase" the fuel cell will be able to power its own BOP, **if Fuel cell power OUT voltage is higher than External Power Supply voltage.**
3. By setting the *BOP Switch* to 0, the External Power Supply will power the BOP at all times including "Running Phase".

3 OPERATING PROCEDURES

3.1 SETTING UP PROTIUM-1000

1. Mount Protium-1000 securely in 1 of the 2 recommended orientations.
2. Connect your Hydrogen gas supply to the *H2 gas inlet connector*. Make sure that your Hydrogen gas supply is OFF at this stage.
3. Connect the purge tubing to the *H2 gas outlet connector*. **Caution:** Channel the purge tubing to the back of the cooling fans and far away from the oxidant blower inlet.
4. Connect an external power supply to the *external power supply receptacle*. Make sure that it is turned OFF at this stage. Set the *BOP switch* to 0 if you want the external power supply to continue powering PROTIUM-1000 BOP throughout the entire operation.
5. Connect your load to the *Load power connector*. **Tip:** check that the polarity is correct. It is also advisable to put an ON/OFF switch at your load and ensure that it is turned OFF at this time.
6. Turn on your PC and connect the communication USB cable to a USB port. Download the Spectronik Data Acquisition (DAQ) GUI PC application from the Protium-1000 product webpage. Install the app and follow the instructions in its user guide.

Tip: You can also use any serial data application like Hyperterminal. Set the parameters (57600 baud rate, 8 data bit, No parity, 1 stop bit).

Reminder: Ensure that all gas tubing and electrical wire connections are firm and secure.

PROTIUM-1000 is now ready to turn on.

3.2 TURNING ON PROTIUM-1000

1. Turn on the external power supply. Wait for 5s. A welcome header should appear in the GUI. LED will blink at 10%.
2. In the GUI, click the "start" command or type the word "start" and <enter> using the keyboard function. Alternatively, press and hold on *ON/OFF push button* for more than 2s. PROTIUM-1000 will enter its "Starting Phase" and the message "Low H2 supply" should appear.
3. Turn on your Hydrogen gas supply. **Caution:** Ensure that the gas delivery pressure is 0.5-0.7 barg.

Insufficient delivery pressure may cause cell flooding and drop in performance, while excessive pressure may rupture the fuel cell membrane, causing dangerous gas leakage and irreversible cell damage. Ensure that your pressure regulator can provide Hydrogen gas flow rate of more than 15L/min.

4. PROTIUM-1000 will do a series of gas purging and internal diagnostic checks. If everything is normal, the fuel cell will enter its "Running Phase" – indicated by the message in the GUI and a solid white LED.

PROTIUM-1000 is now ready to power your application.

3.3 POWERING YOUR LOAD WITH PROTIUM-1000

1. Turn ON your load and draw power as per normal. **Caution: never pull the fuel cell voltage below 18V or draw power beyond 1000W.**

If hybrid battery is connected at the load, PROTIUM-1000 will provide up to its maximum rated output and the rest is augmented by the battery. The total power available depends on the capacity of the battery.

Mode	Range	Ramp-rate
Constant Voltage Load	Open circuit voltage to 18VDC min or 1000W max	-1VDC/second
Constant Current Load	0A to 55A or 1000W max	+2A/second
Constant Power Load	0W to 1000W max	+100W/second

2. During Running Phase, the following live status of the fuel cell can be monitored from the GUI.

Parameters	Description
FCV	FC voltage [V]
FCA	FC current [A]
FCW	FC power [W]
Energy	Energy delivered by the fuel cell during this operation [Wh]
FCT1	FC temperature at location 1 [°C]
FCT2	FC temperature at location 2 [°C]
FAN	Cooling fan duty cycle [%]
BLW	Oxidant blower duty cycle [%]
H2P1	H ₂ supply pressure [Barg]
H2P2	H ₂ pressure in FC [Barg]
Tank-P*	Gas tank pressure [Barg]
Tank-T*	Gas tank temperature [°C]
DCDCV*	Converter voltage [V]
DCDCA*	Converter current [A]
DCDCW*	Converter power [W]
BattV	External power supply voltage [V]

*with purchase of optional Spectronik accessories (gas tank, pressure regulator and DC/DC converter)

3.4 SHUTTING DOWN PROTIUM-1000

1. Turn OFF your load. The cooling fans will turn faster to cool down the fuel cell, before returning to their minimum speed.
2. In the GUI, click “end” command or type “end” and <enter> using the keyboard function. Alternatively, press and hold the *ON/OFF push button* for more than 2s.

The message “Shutdown Initiated” will appear in the GUI and PROTIUM-1000 will enter its “Shutdown Phase”. The system is now OFF. LED will blink at 60% on standby awaiting the next start-up command.

3. If you do not intend to restart the system soon, turn OFF your Hydrogen gas supply and remove the Hydrogen gas tubing from the *H₂ gas inlet connector*. **Caution: some remaining gas in the tubing will be released into the atmosphere.**
4. Turn OFF the external power supply.

PROTIUM-1000 is now ready to be kept for storage.

4 SYSTEM MONITORING, PROTECTIONS & MANUAL CONTROL

4.1 MANUALLY CONTROLLING THE PROTIUM-1000

The PROTIUM-1000 comes with in-built firmware control that is optimized to bring out its best performance over the applicable ambient environment range. In normal use-case scenario, there is no need for user to fine-tune the parameters. For advanced user who wishes to control the fuel cell manually, the following commands can be entered via Hyperterminal or the GUI's keyboard function.

Command	PROTIUM-1000 action
start <enter>	Starts the system
end <enter>	Enters normal shutdown phase
ver <enter>	Displays the firmware version
f <enter>	Return to automatic cooling fan control
b <enter>	Return to automatic oxidant blower control
p <enter>	Open the Hydrogen purge valve for 2s. This is useful to remove excess water if cell flooding is suspected due to decreasing power output.
= [equal]	Increase cooling fan speed by 5% [manual control]
- [hyphen]	Decrease cooling fan speed by 5% [manual control]
0	Increase cooling fan speed by 1% [manual control]
9	Decrease cooling fan speed by 1% [manual control]
]	Increase oxidant blower speed by 3% [manual control]
[Decrease oxidant blower speed by 3% [manual control]

Tip: you may also long press the *ON/OFF push button* by >2s to turn ON/OFF the system instead of entering "start" and "end" command via the GUI.

4.2 SYSTEM WARNING & PROTECTIONS

PROTIUM-1000 has several in-built protections. The LED will flash and error message will appear in the GUI. Follow the basic troubleshooting guide below. Most errors should be rectified once the suggested corrective action has been done and the system restarted.

If the error persists, contact support@spectronik.com.

4.2 SYSTEM WARNING & PROTECTIONS (Cont.)

Warning messages during “Starting Phase”:

Message	Meaning/ Corrective Action
"Gas Tank Not Detected" *	Either the gas tank communication cable is not connected or the tank is empty.
"Gas Tank Pressure Low" *	There is less than 20 Bar remaining in the gas tank.
"Gas Tank Insufficient Pressure" * ●	There is not enough pressure in the gas tank to start.
"Error: Gas Tank at High Temperature" * ●	The Gas Tank internal temperature is above 60°C. Please check for abnormalities.
"Low H2 Supply"	Hydrogen supply pressure is low and the system will wait up to 1 min for correction. Please check and correct the delivery pressure.
"Error: Low H2 Supply" ●	Hydrogen is not correctly supplied within the stipulated time limit. Check and ensure sufficient Hydrogen supply and correct delivery pressure. Restart the system.
"Over Pressure"	Hydrogen supply pressure is too high and the system will wait for 1 min. Reduce the delivery pressure.
"Error: Over Pressure" ●	Hydrogen is not properly supplied within the stipulated time limit. Check and ensure sufficient Hydrogen supply and correct delivery pressure. Restart the system.
"High Temperature"	Stack temperature is too high and the system will wait for 1 min.
"Error: High Temperature" ●	Disconnect everything and wait for system to cool down and restart after 10min. If the problem persists, internal temperature sensor might have been compromised. Contact Spectronik.
"Error: FC Over Cooled" ●	Stack temperature is too low. Wait for ambient temperature to increase and restart the system.
"FC Sealing Compromised" ●	Possible stack leakage. Check and ensure all gas tubing and connectors are securely connected.
"Error: Low Voltage" ●	Stack open circuit voltage is too low. Check and ensure sufficient hydrogen supply and correct delivery pressure. Restart after 1 min.
● <i>Emergency Shutdown = "Abnormal Shutdown" would be activated</i>	
* <i>with purchase of optional Spectronik accessories (gas tank and pressure regulator)</i>	

4.2 SYSTEM WARNING & PROTECTIONS (Cont.)

Warning messages during “Running Phase”:

Message	Meaning/ Corrective Action
"High Temperature" ●	Stack temperature is too high. The fuel cell power output to load will be temporarily disconnected for 5s for system to recover. LED will blink. Reduce your load.
"Error: High Temperature" ●◎	Stack temperature is too high. Disconnect everything and wait for system to cool down and restart after 10min. If the problem persists, internal temperature sensor might have been compromised. Contact Spectronik.
"Low Temperature" ●	Stack temperature is low. LED will blink.
"Error: FC Over Cooled" ●◎	Stack temperature is too low for operation.
"Low Voltage" ●	Stack Voltage at minimum threshold of 0.6V/cell.
"Error: Low Voltage" ●◎	Stack Voltage below safety threshold limit.
"Low H2 Supply" ●	Hydrogen supply pressure is low and the fuel cell power output to load will be temporarily disconnected. LED will blink. Check and ensure sufficient Hydrogen supply and correct delivery pressure.
"Error: Low H2 Supply" ●◎	Hydrogen supply pressure is too low. Check and ensure sufficient Hydrogen supply and correct delivery pressure. Restart the system.
"High H2 Supply Pressure" ●	Hydrogen supply pressure is too high and the supply valve will be temporarily shut off. LED will blink at 80%. Reduce the delivery pressure.
"Error: High H2 Supply Pressure" ●◎	Hydrogen supply pressure is too high. Check and ensure sufficient Hydrogen supply and correct delivery pressure. Restart the system.
"Low Battery" ●	The External Power Supply is at below 15V.
"Gas Tank Running Low" * ●	The pressure in the gas tank is below 20 Bar.
"Gas Tank Depleting" * ●	The pressure in the gas tank is below 10 Bar.
"Error: Gas Tank at High Temperature" * ●◎	The Gas Tank internal temperature is above 60°C. Please check for abnormalities.

◎ *Emergency Shutdown = "Abnormal Shutdown" would be activated*

● *LED flashing at 80% to alert warning in the running*

* *with purchase of optional Spectronik accessories (gas tank and pressure regulator)*

4.2 SYSTEM WARNING & PROTECTIONS (Cont.)

Other messages:

Message	Meaning
Fan PWM auto	Cooling fans control is in auto mode
Blower auto	Oxidant blower control is in auto mode
Mileage	Cumulative Watt-Hour of the system
Shutdown initiated	Entering "Normal Shutdown Phase"
Abnormal Shutdown initiated	Entering "Abnormal Shutdown Phase" due to an error
System off	System is turned off and ready to restart at the next command

LED status:

Phase	Blink % (at 1Hz)	Meaning
Power ON	10%	5s after start-up power is provided into the fuel cell controller, LED will blink at 10%, indicating that the system is ready to receive its "start" command
Starting Phase	40%	Executing "Starting Phase" procedures
Running Phase	100%	System in normal "Running Phase"
Running Phase	80%	System warning during "Running Phase"
After shutdown	60%	System off due to normal shutdown and on standby for the next "start" command
After shutdown	0%	System off due to abnormal shutdown

5 MAINTENANCE AND STORAGE

5.1 MAINTENANCE FOR PROTIUM-1000

When not in use, Spectronik recommends that PROTIUM-1000 is reconditioned at least once a month.

1. Set up PROTIUM-1000 as per instructions in Section 3, using a DC electronic load in lieu of your regular load.
2. After the system enters "Running Phase", set constant voltage (CV) load of 18V and run the system for 1h. The fuel cell should recover to its maximum rated power output.

PROTIUM-1000 is now ready for usual operation or can be stored again for future use.

5.2 STORAGE

Keep PROTIUM-1000 in an open, cool (standard room temperature of 25°C) and dry place.