Chapter 8 : Integration

Integration Overview

Integration refers to the assembly of detector lines and the testing of components and full systems during and after assembly. Testing of subsystems is performed during assembly in order to construct detector lines ready for deployment. Written procedures will be followed for each integration task, and results will be recorded in databases and on follow-up cards.

All items used to constitute the line are defined in accordance with the PBS, built and tested by the group responsible for that item (e.g., Optical Module or LCM), and delivered to the integration group ready for use, accompanied by their follow-up cards and database for quality control.

If any item fails during the integration process, it will be sent back to the group responsible for it, for repair or replacement. **No repairs will be made by the integration group during assembly.**

The logistical activities required for each object begin with the manufacture of the object and proceed through transportation and storage, assembly and testing, transportation to the deployment site, loading onto a ship and deployment at the ANTARES site. An "audit trail" must be maintained over the lifecycle of the object by means of a relational database and the physical follow-up cards.

The first line to be deployed will be the prototype sector line. This line consists of a single sector of 5 storeys with its associated SCM/SPM. It will be connected to a Junction Box and linked to the shore station with a minimal data acquisition system. The prototype sector line will be used for a final verification of the detector design and an early identification of possible problems. The prototype sector line will also be the first sector and the first line to pass through the assembly and test procedures.

The assembly, testing and calibration of the prototype sector line will be performed at CPPM in Marseille. A dedicated facility will be established for the assembly and tests of the lines for the full detector at a location in La Seyne sur Mer. A dark room big enough to accommodate a complete sector will be required at this facility.

The final line will be assembled, starting at the bottom of the line, by adding storeys one at a time to complete individual sectors. The sector is then fully tested and calibrated before assembly continues for the next sector. When the line is complete, a further test is performed with the whole line immersed in a few meters of water

Component integration

The final assembly operation will start from a set of components pre-assembled in the various collaboration institutes and in industry. The list of such components arriving in the Line Integration Facility is as follows:

- Optical Module (OM)
- Optical Module Frame (OMF)
- Local Control Module (LCM)
- Electro-Mechanical Cable sections (EMC)
- Electro-Mechanical Cable penetrators
- String Control Module/ String Power Module (SCM/SPM)

- Bottom String Socket (BSS)
- String Buoy
- LED Optical Beacon
- Hydrophones

Storey integration

The integration of the detector line consists of the step-by-step assembly of **storeys.** The line is divided into 6 sectors, each with 5 storeys linked by an Electro-Mechanical Cable. The goal is to assemble each sector and test and calibrate it before integrating it into the line. All the lines are identical. All of the storeys have the same basic structure, but some of them have added functionality (MLCM, hydrophone, optical beacon).

The sectors on a line will differ because of the location of the additional instrumentation. These locations are defined by the instrumentation group.

The cabling of each storey is different. A schematic will be prepared for each of them (eg. schematic of Line1). During the assembly and tests, relevant parameters and test results will be entered in the databases and the follow-up cards will be filled out.

A storey is made of :

- A mechanical structure (OMF) with mechanical pieces to hold the items;
- 3 Optical Modules;
- 1 LCM or MLCM container with its electronics
- 1 section of electromechanical cable EMC
- 1 hydrophone or 1 LED Optical Beacon (for certain storeys).

The assembly of a storey is made with the OMF in a vertical position.

Sector integration

The assembly of the sector will begin by the bottom storey with the EMC coming from the previous storey (or BSS for the first sector).

Storey assembly protocol

1. LCM compass calibration in OMF
2. Fix up and down EMC on OMF
3. Put OMF on its support
4. Put LCM in OMF
5. Put LCM flange above LCM
6. Put the penetrators on the flange
7. Connect wires and fibres from EMC
8. Connect wires and fibres from LCM
9. Control cabling and test (attenuation fibres, insulation, continuity,…)
10. Flush with dry air or nitrogen to prevent humidity

11. Close LCM

12. Integrate OM on its support (*could be done anytime before)*

13. Integrate OM on OMF

14. Connect OM on LCM

15. And as a function of the storey:
    - Integrate hydrophone
    - Connect hydrophone on LCM
    - Integrate Optical Beacon
    - Connect Optical Beacon on LCM

After the assembly of the five storeys, the sector will be tested.

Line integration

The line is assembled starting from the SCM and SPM at the bottom of the line. The assembly of the line must be carried out near the sea, because it will be difficult to transport full lines due of their dimensions.

Line assembly protocol

- Integrate components on BSS
- Assemble storeys and sectors
- Transfer line to deck support
- Lay the lower100 m EMC on the deck support above the other EMC

The line is ready for line tests.

Manpower

People in charge of the assembly have to take delivery of objects, fill in the database and follow-up cards, and take care of storage, handling, mechanical assembly, optical and electrical connections, and optical and electrical tests.

This requires 4 full time persons for the assembly and logistics.

People must be trained for these jobs and the personnel should not change frequently. People should be expected to work for periods of at least 3 months (about one line assembly).

A stable ''hard core'' of 2 persons attached to the assembly is necessary for the duration of the project.

Number of fibre connections in a line

Storey	Fibres not connected		EMC down	Connected	fibres
	EMC down	EMC up	to EMC up	to LCM	
LCM 30	17		0	4	
LCM 29	16	17	1	7	
LCM 28	15	16	2	7	
MLCM 27	15	15	0	12	
LCM 26	16	15	2	7	
Total Sector 6	**79**	**63**	**5**	**37**	**42**
LCM 25	14	16	3	6	
LCM 24	13	14	4	7	
LCM 23	12	13	5	7	
MLCM 22	12	12	3	12	
LCM 21	13	12	5	7	
Total Sector 5	**64**	**67**	**20**	**39**	**59**
LCM 20	11	13	6	6	
LCM19	10	11	7	7	
LCM 18	9	10	8	7	
MLCM 17	9	9	6	12	
LCM 16	10	9	8	7	
Total Sector 4	**49**	**52**	**35**	**39**	**74**
LCM 15	8	10	9	6	
LCM 14	7	8	10	7	
LCM 13	6	7	11	7	
MLCM 12	6	6	9	12	
LCM 11	7	6	11	7	
Total Sector 3	**34**	**37**	**50**	**39**	**89**
LCM 10	5	7	12	6	
LCM 09	4	5	13	7	
LCM 08	3	4	14	7	
MLCM 07	3	3	12	12	
LCM 06	4	3	14	7	
Total Sector 2	**19**	**22**	**65**	**39**	**104**
LCM 05	2	4	15	6	
LCM 04	1	2	16	7	

LCM 03	0	1	17	7	
MLCM 02	0	0	15	12	
LCM 01	2	0	17	6	
Total Sector 1	**5**	**7**	**80**	**38**	**118**
SCM	**0**	**2**		**19**	**19**
Total :	**250**	**250**	**255**	**250**	

Number of fiber connections in a line : 505 with 174 for DAQ DWDM

Logistics

Logistical aspects of the 0.1 km^2 project involve a wide range of activities which include:

- production scheduling and planning
- stock control, demand forecasting, inventory control
- distribution, availability of warehouses, storage, stock handling
- transportation

These activities require detailed and current information on the status of stock availability and production levels. The people responsible for the ANTARES project logistics must coordinate all of these tasks in such a way that demand is met with supply, and bottlenecks are avoided. This will require close collaboration with individuals responsible for specific components and objects.

The detailed nomenclature of the objects is defined in the Product Breakdown Structure (PBS), which assigns a serial number to each object. Computerised management of the follow-up cards will be established for each element of the detector, in the ANTARES database.

Description of Logistical Activities

Manufacture

During the lifecycle of each object an "audit trail" must be maintained such that, at any time, the precise location of that object can be immediately determined along with the history of the object (fabrication, performance on test bench, etc.). In order to achieve this, a computerised system involving a relational database augmented by physical "follow-up cards" is foreseen.

Transportation to the storage site

After production and testing, each object (group of objects) must be transported to its place of storage which should be close to the site where its integration into detector subsystems will take place.

Storage

Given below is an example of the storage volumes required for the storage of the optical modules and the mechanical storeys.

OMF	1 storey	1 sector	1 line	3 lines	10 lines
Number of objects	1	5	30	90	300
Volume (m^3)	0.5	2.5	15	45	150
OM	1 storey	1 sector	1 line	3 lines	10 lines
Number of Objects	3	15	90	270	900
Volume (m^3)	0.3	1.5	9	27	9

For planning purposes, to precisely evaluate the requirements that will be made on the infrastructure, detailed information for each group of objects will need to be supplied to those in charge of logistics by the individuals responsible for the specific object.

Assembly and testing

The assembly of each detector element (object, subsystem) will have to be clearly defined and documented so that the final assembly of the next item in the hierarchy (subsystem, system) does not suffer from any ambiguity. The follow-up cards described previously will be associated with assembly procedures and will be used to reduce errors in these areas.

Each person responsible for a detector object must define the equipment for the measurements and the tests to be carried out during and after assembly. These tests will be performed according to pre-determined procedures. These operations and their results will be described in the follow-up cards and in the object database.

Transportation to the deployment site

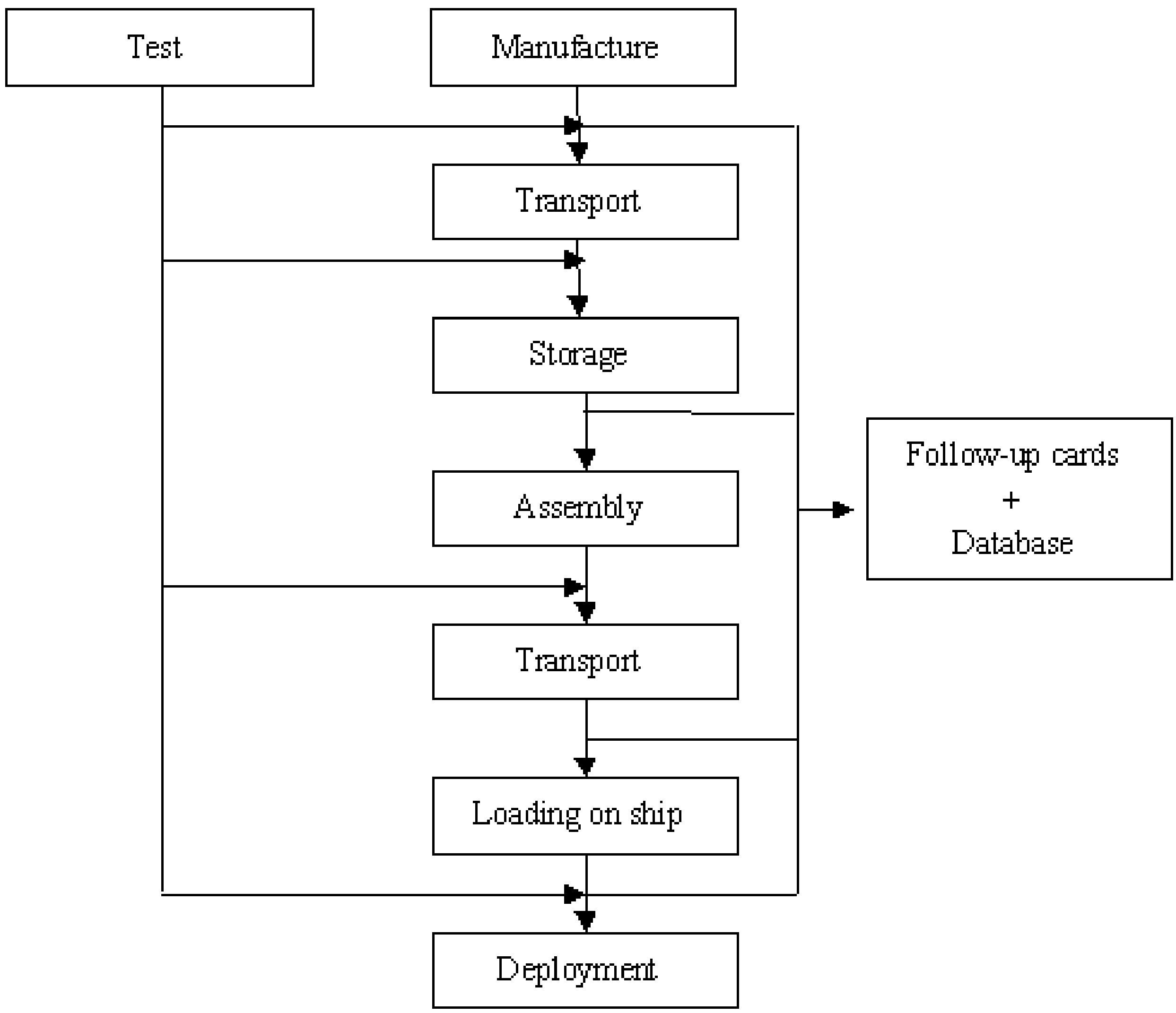
In order to keep the movement of each sector to a minimum, the assembled lines should be transported directly from the assembly site to the deployment site.

Loading on ship for deployment

This phase of the integration operation concerns the loading of the line, ballast and equipment onto the ship. Here it will be necessary to pay particular attention during handling operations to avoid mechanical shocks to the detector hardware. Loading must be carried out according to established procedures and in the presence of the individual responsible for the operation. The loading operation will terminate with a final check of the equipment according to a pre-determined checklist.

Deployment

The deployment phase will be subject to specific procedures written by the person in charge of the sea operations.



ANTARES Logistical Activities

The Prototype Sector Line (PSL)

The ANTARES collaboration will construct a prototype 'sector line' to be deployed at the ANTARES site in early 2002. The sector line will allow verification of the 'final' design, in the final environment, using prototype electronics boards. It should identify any problems as early as possible, in order to correct them before the production of the full 0.1 km^2 detector.

The sector line will be deployed only after the sector tests and the subsequent line tests have been completed successfully. The sea deployment of the sector line will allow testing of many aspects of the design which would not be possible in onshore tests. These aspects include:

- deployment/recuperation procedure
- power distribution via the sea electrode
- line movement: sway, twist, stretch, oscillation
- acoustic positioning and absolute positioning
- *in situ* time calibration with OM flashers and optical beacons (with real scattering and absorption effects)
- medium term corrosion effects
- onshore versus offshore trigger comparisons
- trigger rates and data volumes in final conditions
- evaluation of system reliability

At least three periods, of 8 hours each, of uninterrupted acquisition of unfiltered data are required to meet the objectives of the prototype line. A relative timing accuracy of 0.5 ns should be obtained between storeys. The OMs should be aligned with an accuracy of 20 cm.

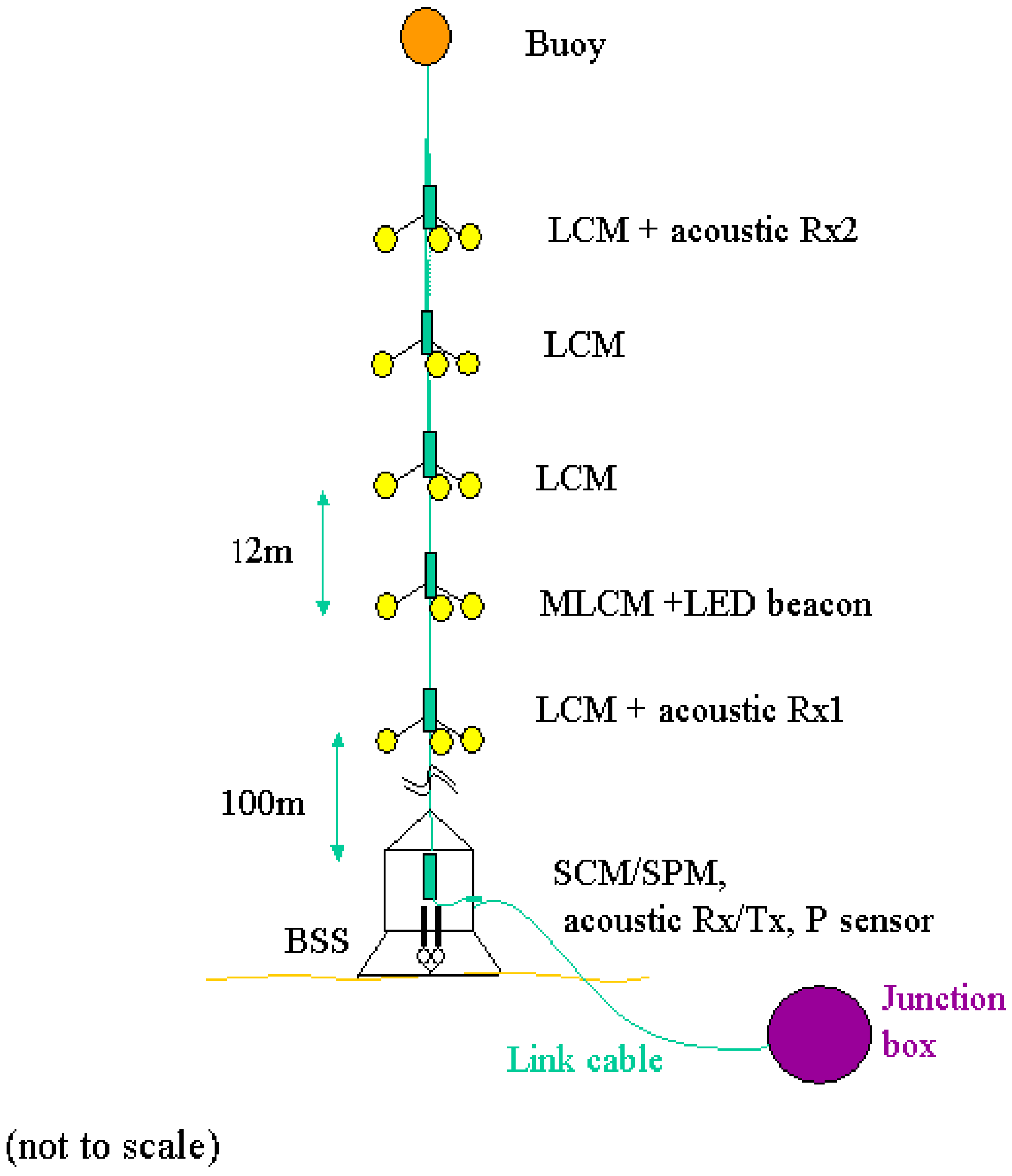
The sector line will consist of a single sector of 5 storeys, with the associated SCM/SPM and junction box, and a minimal DAQ system at the shore station. The lowest storey will be at the nominal position, 100 m from the sea bed, and the spacing between storeys will be the standard 12 m.

The floater buoy will be 12 m above the top of the 5th storey. The ballast/BSS and buoyancy of the floater will be appropriate for the reduced size of the line. It will be connected via the 'final' junction box and electro-optical cable to the shore station.

The sector line will also incorporate the elements necessary to test the acoustic positioning system: the standard acoustic receivers and transmitters at the base of the line, receivers at the 1st and 5th storey, and an optical beacon at the 2nd storey.

The sector line will be recovered after 2-3 months of continuous sea operation.

A first version of the instrumentation line, equipped with two storeys, will be deployed at the same time as the sector line. It will incorporate a laser and a LED Optical Beacon to illuminate the sector line.



Schematic view of the prototype sector line

Line Integration Facility

A dedicated facility will be established for the line integration and testing. This facility will be in an existing building in La Seyne sur Mer located to minimise transport to the ship loading dock.

The facility should accommodate the following procedures:

- reception and storage of the sector elements (OMs, LCMs, OMFs, etc.)
- assembly of the sectors
- testing of the sectors, including slow control, compass, tiltmeter, and acoustic systems.
- calibration of the sectors: gain of each OM, relative timing calibration between OMs, etc.
- monitoring of long-term behaviour of the sectors in realistic conditions: the photomultipliers switched on and stimulated by random light sources simulating the *in situ* background light from ^{40}K decay and bioluminescence.

The main components of the line integration facility will be:

- a mechanical system to facilitate assembly of the line. This system will comprise rails hanging from the ceiling and a number of assembly and testing areas. This configuration will allow one sector to be assembled while another is being tested and calibrated. Line elements are transported along the rails on trolleys; each trolley is equipped with a hook which can be attached to an OMF or to the cable.
- a large dark room equipped with large access doors for sector testing.
- a control room.
- a cooling system for the electronics consisting of a water coil which can be fixed on any electronic element.
- two light sources installed in front of each OM: a very fast light source for timing calibration tests, and a random light source for the ^{40}K simulation (for long term tests).

It must be stressed that sector testing is intended to verify the performance of properly-functioning detector elements. Any element failing these tests will be returned to the group responsible for that element; it will not be repaired at the test facility.

Sector test and calibration scenarios

Test scenario

At the start of the integration procedure, the connections between the sector elements will be tested passively: electrical continuity in the case of electric cables and attenuation in the case of optical fibres.

After assembly, the sector will be transferred to the darkroom where the OMs will be positioned precisely using a specific mechanical system. In order to obtain an accurate timing calibration, the OMs must be placed in front of the light sources with a precision of about ±10 cm. After this calibration, the sector will be connected to the SPM and the SCM for further tests.

With the sector connected to the DAQ, it will be possible to check the power consumption, the slow control, the compass, the tiltmeters and the acoustic beacons. This is not a calibration exercise, but simply a control of the behaviour of these sector elements. To perform an accurate analysis of the system, it is mandatory that the individuals responsible for the different sub-elements provide a check list and a set of values that represent typical performance parameters for that element.

Calibration scenario

If the sector tests are successful, the OMs can be calibrated via the following sequence:

1. Switch on the OMs and check their dark counting rate.
2. Calibrate the OM gain. A single photoelectron light source will be installed in front of each OMF and the measurement performed for several values of the high voltage. A pulse-height spectrum will be obtained, giving the most probable SPE charge for a given high voltage, and the peak to valley ratio.
3. Calibrate the relative timing by illuminating all the OMs by a synchronous light source with a very short pulse width.
4. Record SPE events using the ARS.

All these measurements will be saved in the ANTARES database.

Long term test

The final test which is foreseen is a long term test in which all the OMs are illuminated with a light source typical of the *in situ* background light (^{40}K decays and bioluminescence). This test is well-suited to debug the full sector line (including the trigger and the on-shore DAQ system). The long term test will be part of the systematic tests of all of the sectors.

Test of the prototype sector line

The test procedure for the prototype sector line consists of a series of three to five "cold starts" followed by periods of running and calibration. Results of each test will be compared to those of previous tests and with measurements performed in the laboratory. A policy whereby no identified malfunction is left unexplained or uncured is proposed. The test of the prototype sector line is expected to take between two and four weeks, depending on the number of problems found.

The greatest uncertainty concerning the sector line test is the time it may take. Even though each sector will have been extensively debugged beforehand, all functions will need to be tested again and results compared to those obtained in the laboratory, as transportation and handling may have caused damage. Each individual responsible for the development of a part of the line must issue a check-list giving nominal values and acceptable limits for all measurable parameters relevant to that detector sub-system.

Test of full detector lines

The goal of these tests is to verify the operation of the line immediately after assembly and directly before deployment at the ANTARES site. The line is immersed in four to five metres of water at the side of a pier. All of the modes of operation will be tested, except those requiring the PMTs to be turned on. Data produced during these tests will be analysed online in order to detect any malfunction immediately. A test station must be installed in close proximity to the pier in a room with sufficient power and cooling, and a telephone and an ethernet connection.

For the full detector lines, a level of malfunctions beyond which the line is retrieved and repaired before restarting a full test must be defined.

The standard line test will be more limited in scope than the prototype sector line test and will be defined once the prototype line has been tested and operated successfully. In particular, specific tests are foreseen to check the large number of connections on the full lines.

Hardware and software needs

In order to test the lines under realistic conditions, the control station for the line tests must be a model of the shore station. It will need a Slow Control system, DWDM demultiplexing, a readout system and a clock system. The software used at the test station must be identical to that used at the shore station. This software will include tools to diagnose potential malfunctions, such as the absence of response to a Slow Control order or unexpected measured values from sensors.

For all the tests, the PMTs must be disabled or powered on at a low voltage only. It may be desirable to turn the PMTs on at a voltage much lower than the nominal one in order to test the OM-LCM connection.

It is not practical to test the lines by connecting them to the Junction Box. A short cable, the LINE_TEST cable, about 20 m in length, equipped with a wet connector at one end and a dry connector at the other end will be used to connect the SCM to the control station. The readout request, normally sent from the Junction Box, will be simulated by a pulse generator controlled by the Slow Control system.

The optical power loss due to connections in the JB and attenuation in the fibres must also be simulated.

A dedicated power supply will deliver the required 1000V AC to the SPM. This supply will be controlled via the Slow Control system in a similar way to the shore station power supply.

The test station will operate in parallel with the shore station, because lines which have already been deployed must be read out while other lines are being assembled and tested.