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S. Colonges, D. Real, D. Calvo, P. Musico, G. Pellegini, P. Jansweijer, V. van Beveren, T. Chiarusi, C. Bozza, C. Nicolau, et al.

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## Electronics reliability methods for neutrinos telescopes: the KM3NeT case

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**ABSTRACT:** The KM3NeT collaboration is building a deep-sea neutrino observatory in the Mediterranean Sea equipped with thousands of glass spheres, hosting the so-called digital optical modules, with an instrumented volume of several cubic kilometers. Reliability of the components used in the construction of the detectors is of extreme importance as the deployed detection units, each one composed of 18 digital optical modules, will not be accessible for any kind of maintenance and the detector should be functional for a period longer than 10 years. This work presents the different reliability methods used in KM3NeT to assess and improve the reliability of the electronics housed in the Digital Optical Modules of KM3NeT.

**KEYWORDS:** Charge transport and multiplication in gas; Instrumentation for synchrotron radiation accelerators

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### 1 Why reliability?

The KM3NeT observatory [1] will be the world’s biggest and most complex underwater infrastructure network, with around 200000 PMTs necessary for the two sites [2, 3] (ARCA and ORCA, off the shores of Capo Passero and Toulon). There will be more than a million of components (electrical, electronic [4, 5], mechanical, optical) to manufacture and integrate, representing close to 400 different product types, with different configurations, electronic improvements and network layout. Moreover, sea science instruments will be deployed on both sites. All of these configurations should be considered for Reliability, Availability, Maintainability, and Safety (RAMS) studies (see figure 1).

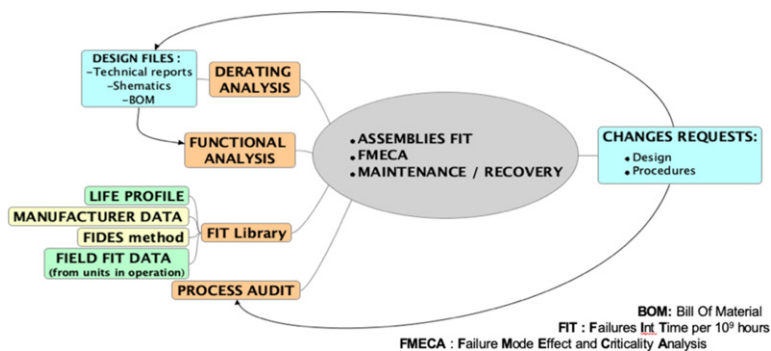
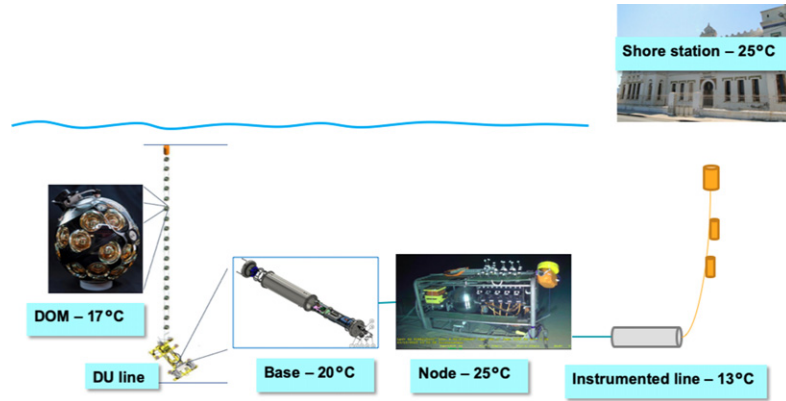


Figure 1. RAMS method.

The fundamental input parameter for a reliability analysis is the life profile (see figure 2), which includes ON/OFF cycles, temperature and humidity cycles, vibrations, corrosion, studies, etc . It is necessary to consider these parameters (defined by analysis or using measurement on assemblies already deployed in the sea or in laboratories) applied inside each sub-assembly (digital optical module [6–8], base module, node, instrumentation unit or shore station. . . ) for the calculations of



**Figure 2.** Site life profiles.

reliability, which gives an additional level of complexity for the analysis. The detectors are deployed between 2500 and 3500 m deep in France and Italy, so the constraints in terms of pressure and corrosive environment and access difficulties are high. One of the major KM3NeT requirements is to maintain the highest possible level of PMT availability during 10 to 20 years and avoid the need for repairing campaigns. Moreover, it must be identified the single point failure paths in order to avoid a major loss of detector availability. This is an exciting challenge due to the complexity of the system!

## 2 How we proceed?

A reliability study starts with the analysis of the technical design report, schematics, and bill of material. First, it is performed the derating analysis in order to identify the electrical stresses applied to each component of the bill of material with respect to the maximum values recommended by the manufacturer. Then, the failure rate for each component is calculated from the manufacturer data or using a reliability handbook or collected from units already in operation, considering always the applied life profile. Finally, the assembly or overall infrastructure failure rate, which is the occurrence parameter used for the Failure Modes, Effects and Criticality Analysis (FMECA) [9], is calculated using all individual components' failure rates. When weakness are pointed out or necessary improvements in terms of reliability are identified, recommendations for change can be made in order to improve the design, select components with higher derating or improve processes (manufacturing or other).

For KM3NET, it has been chosen the FIDES reliability handbook for failure rate calculations, because it is the most recently updated standard, and there is a FIDES active working group. This method has been initiated by the European aeronautic, defense and space industry. FIDES considers, as other standards do, the technology of the components, and additionally the life profile, or in other words, the environment, the over-stress applied on components, the users interaction with the system, and the processes applied during the project life cycle. The process contribution is considered at each project phase, affecting the failure rate by a multiplier factor from 1 to 7.

At Astroparticle and Cosmology Laboratory, an Excel home tool has been developed which allows for collecting in a library all the reliability data from FIDES or manufacturer and performs automatic calculations for product and assemblies from the system product breakdown structure definition. The bill of material of each assembly is imported in this tool. As the result of the derating analysis and the product life profile analysis, a dedicated reliability model is applied to each component. The Excel tool calculates the FIT, the failure risk and the quantity of failed items expected for a given period. Moreover, the tool allows for identifying generic or specific failure modes for each product, with description by the design team and expert of the possible end effect, root causes, detection and mitigation procedures. The criticality automatically calculated gives warning on high occurrence or severity failure modes.

The Excel tool calculates the sum of failure rates. Moreover, any redundancy can be taken into account for the calculations. In order to reach an accurate analysis for system availability analysis, it is used the reliability block diagram tool. The reliability block diagram allows for considering all the component that can contribute to a single pixel (PMT) failure and calculate the “serial” FIT for a single pixel.

Ceramic capacitors are the components with major contributors to the boards’ failure rate, but it can be expected a real failure rate lower. Indeed, the models were defined in 2009, but the manufacturing processes have been significantly improved since.

### 3 Improving the reliability

In order to reach a high availability level, high reliability components have been selected at least for critical functions. We implement protection against failure propagation, and it has been applied European cooperation for space standardization freely available for components derating. Components temperature dissipation improvement has been also considerate. By applying simple recommendations, the probability of failure has been reduced up to 40 per cent between in the first prototype and the final version of some boards.

For single point failure, it is necessary to implement redundancy or identify recovery procedures and recoverable components. Firmware and software failure rate is not included in the failure rate calculation, but anyway this is included in the FMECA analysis. At least remote programming, and rescue memory have been implemented.

The lifetime of a population of products could be seen as a bathtub curve with three periods: an infant mortality period with youth failure due to design or manufacturing defects, followed by a normal life period (also known as “useful life”) with a relatively constant and random failure rate and concluding with a wear-out period that exhibits an increasing failure rate. In order to eliminate youth failure, a Highly Accelerated Stress Screening (HASS) is performed for all the boards as closed as possible to the best industry practices. To do so, we perform first a Highly Accelerated Life Test (HALT) to found the limits of the boards (5 boards sample) then we apply a margin of 20 per cent on extreme values in order to define HASS maximum values. For the HASS, next to a first cold cycle, a 16 hours burn-in at 55 to 70 °C and then up to 24 temperature cycling of 3 h 30 duration each are performed. A light functional test during cycling allows identifying failures when they occur. Additional constraints are added, like electrical power ON/OFF during dwell time and

vibrations screening. Moreover, to avoid youth failure, manufacturing and integration procedure are key for reliability. For example, special care should be taken for penetrators assembly and verification in order to avoid water ingress.

#### 4 Failures tracking

To be able to reach a high reliability, and understand failure modes and cause, monitoring is fundamental. Tracking web tools have been developed in order to monitor DOMs. This real failure data could be integrated in the Excel tool to calculate the real failure rate and compare with evaluations. When failures are detected, they are recorded in the KM3NeT database, and a non conformance review boards is organized by the technical coordinator in order to analyze failures.

#### 5 Conclusion

The analysis is based on worst case scenarios, and it is pessimistic. Most of the random failures and effect will result in only a small degradation and not on the loss of the equipment. Moreover, technology and manufacturing processes are improved continuously, with a favorable impact on reliability. The reliability analysis and enhancement is a great and interesting challenge. The authors suggest that an open discussion about reliability between neutrino telescopes experiments and a share of reliability data would be of high interest.

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