Computer Physics
Communications

Lessons learned from the NEPTUNE power system, and other deep-sea adventures

Harold Kirkham*

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

Elsevier use only: Received date here; revised date here; accepted dat e here

Abstract

The development of underwater science systems presents some challenging technical issues. The best efforts of the engineers and scientists involved are sometimes inadequate, and projects that once seemed straightforward end up being late, or over-budget, or cancelled. This paper reviews some of the lessons that may be learned from the examples of three science projects in the deep ocean: the DUMAND neutrino detector, the H2O observatory, and the power system of the NEPTUNE regional cabled observatory.

lessons learned; mission assurance; ocean engineering; project funding; maintenance

1. Introduction

It is the hope of this paper to support the goal of the VLVnT workshop to advance relevant technologies, by drawing lessons from some past efforts that have much in common with the present endeavor. Those lessons have to do with *mission assurance*: a formal process for ensuring that systems will perform reliably in service.

It is, unfortunately, a characteristic of the "lessons learned" genre that mistakes are emphasized. So it will be with this paper. However, we discuss mistakes in the hope of learning from them (ideally, how to avoid them), and assuredly not in order to assign blame. I sincerely hope I offend no-one.

The three projects I will review here are the DUMAND project (to construct a neutrino telescope), the H2O Observatory (for ocean science), and the power part of the NEPTUNE project.

---

* Corresponding author. Tel.: +1-818-354-9699; fax: +1-818-393-0351; e-mail: harold.kirkham@jpl.nasa.gov

2. DUMAND

The aim of the DUMAND (Deep Underwater Muon and Neutrino Detector) project was to install an underwater observatory 4800 m below the surface at the bottom of the ocean near the Big Island of Hawaii. The array site was 30 km due west from the Kona Coast of the Big Island of Hawaii.

A cable was laid from shore to a junction box, and a first string of detectors was installed from the junction box at the end of 1993. It stopped operating within a few hours, because of a leak. Funding for the project was terminated shortly afterwards.

Now, if you do a short investigation (eg, a quick web-search) into DUMAND, that is about all the information you will find. That is a shame, because the project could be a source of lessons learned.

In fact, the DUMAND project started in 1976 and lasted altogether about 20 years. The many reasons for the closure are given in the SAGENAP committee report, a tough but very instructive document [1].

Unfortunately, we can apply SAGENAP-like criticisms elsewhere. Even, I regret to say, to my own project, NEPTUNE Power.

3. H2O

The Hawaii-2 Observatory (H2O) is a cable re-use project. The work is a collaboration involving the Woods Hole Oceanographic Institute and the University of Hawaii. The site is at a depth of 5000 m, near the midpoint of the old cable.

The H2O project has suffered several problems. During the original deployment in 1998, a support chain broke, and the communication cable and the termination fell to the ocean floor without restraint. Thereafter, the equipment functioned only for a few hours before repair was necessary [2].

The system was never really up to expectations, and though H2O functioned partially for several years (and returned much science data), a further visit was made in September 2003 to install an improved Junction Box and some additional experiments.

Various repairs were made (and the equipment was again accidentally dropped); this all turned out to be unimportant, as a few days later the H2O system stopped sending data. It seems that there may have been a fault to seawater in the power system.

4. NEPTUNE Power

The NEPTUNE project is a scheme to place a large number of science nodes on the Juan de Fuca tectonic plate in the north-east Pacific. The Woods Hole Oceanographic Institute has handled communications, the Jet Propulsion Laboratory, and the University of Washington power. A group in Canada has had responsibility for data archiving.

Until recently, I was the manager of the NEPTUNE Power Group.

A new converter architecture was designed at JPL to step down to 400 V from the 10 kV on the cable. Following software simulations, an engineering model of the converter was built that operated at 3 kV. Following successful tests of this converter, a prototype 10 kV, 10 kW converter was built.

In two attempts in the summer of 2005, the converter did not start satisfactorily. No problem had been observed at 3 kV, and we had not expected an extrapolation of a factor of 3 to reveal anything new. In a paper written a few years ago, we had reviewed three known modes of instability [3], and shown how we were addressing them. Here was what looked like a *new* mode of instability.

Shortly afterwards, the project exhausted its funds, and worked stopped. (Some minor changes to the control system, made during “spare” time, and without funding, have since solved the problem.)

5. The Lessons

I suggest that these various failures are a question of *culture*. In order to succeed, the ocean science community must adopt better methods of mission assurance.

What does this difference of culture arise from? Why are the methods and approaches of different cultures different? In a word, *economics.*

In the US, the economic equation of ocean science has been distorted by the way ship time has been made available. A number of agencies as well as the National Science Foundation support a fleet of 27 ships known as the UNOLS fleet, for University National Oceanographic Laboratory System. As far as I can tell, the fleet is available at no cost or at greatly subsidized cost to ocean researchers.

The National Science Foundation understands that doing ocean science is difficult, and they forgive the occasional failure. A culture of *paying for maintenance* has evolved.

Both DUMAND and H2O have shown considerable skill and ingenuity in building quality systems and stretching the resources. Yet there have been repeat post-deployment ship visits to make repairs. The NEPTUNE power project had insufficient funds even to get to deployment.

The attitude that allows this kind of development begins at the top: the government sponsors accept the occasional failure as the price of doing difficult work *rather than paying the price of more rigorous development*. The attitude extends to project management, who are accustomed to too few reviews and insufficient testing.

I am convinced that with the appropriate level of effort in engineering for reliability, a subsea observatory *can* be designed with acceptable initial cost and acceptable requirements for maintenance. By examining and trading off architectures and designs in the light of reliability engineering, an orderly progress to a successful observatory is made more likely. The design approach, fabrication techniques, functional and environmental testing, handling and deployment are all affected. For a short overview, and a list of references, see [4].

The sponsors' expectations must be "adjusted" until they are in line with this reality. Sponsors must expect to fund a management system that provides an environment in which *reporting* is routine, *reviews* are expected, and *configuration management* is strict. But system developers cannot work in a vacuum: unless the *system requirements* are carefully spelled out (and reviewed and fixed) early on (a process that must involve the scientists), subsystem performance runs the risk of far exceeding needs, or (worse) of not meeting them.

6. Wrap-up

I offer the following suggestions:

- Allow the engineering effort to be managed by someone with a strong background in commercial submarine systems. Accept the increased burden of management, reporting, and testing.
- Keep the sponsor realistically informed of the likely costs. But concentrate on lifetime costs, not just costs up to deployment.
- Don't conclude that you have an optimum design until you have done some trade-offs of alternatives. In a field where no-one has a lot of experience, one's instinct for solutions may mislead. This is part of system engineering.
- Minimize the amount of new technology. If some development effort is needed, be careful how you plan, if it is in the critical path.
- Believe in the long-term benefits of mission assurance. Though the initial costs will be higher than you may be used to, the long term results will pay back the early investment.
- Establish an internal "Lessons Learned" system so that you can, as a collaboration, remember the past and avoid repeating it.

and finally:

- Double the first cost estimates to come from the engineers. We engineers are all optimists.

Acknowledgment

The writing of this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the University of Washington through an agreement with the National Aeronautics and Space Administration.

References

[1] The SAGENAP Report (1996) can be located on the Web at http://www.science.doe.gov/hep/sagenap.pdf

[2] See http://www.soest.hawaii.edu/h2o/

[3] Kirkham, H., Lancaster, P., Liu, C-C., El-Sharkawi, M., Howe, B. (2003, June) "The NEPTUNE power system: design from fundamentals," *Proceedings of the Scientific Submarine Cable 2003 Workshop*, Univ. Tokyo. Also on the NEPTUNE Website at http://neptunepower.apl.washington.edu/

[4] Bowerman, P., Kirkham, H., Fox, G., Lentz, S., Kemski, R., and Howe, B., (2003, June) "Engineering Reliability for the NEPTUNE Observatory," *Proceedings of the Scientific Submarine Cable 2003 Workshop*, Univ. Tokyo.