

# **The NEPTUNE Project - a cabled ocean observatory in the NE Pacific: Overview, challenges and scientific objectives for the installation and operation of Stage I in Canadian waters**

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*Abstract* - NEPTUNE (North-East Pacific Undersea Networked Experiments) will be an innovative network of many sub-sea observatories linked by about 3,000 km of powered, electro-optic cable covering most of the Juan de Fuca Plate (200,000 sq km), North-East Pacific, with shore stations at Port Alberni, BC and probably Nedonna Beach, OR ([www.neptunecanada.ca](http://www.neptunecanada.ca), [www.orionprogram.org](http://www.orionprogram.org), [www.neptune.washington.edu](http://www.neptune.washington.edu)). Each observatory will host and power many scientific instruments on the surrounding seafloor, in boreholes in the seafloor, and buoyed into the water column. Remotely operated and autonomous vehicles will reside at depth, powered or recharged at observatories and directed from distant labs. Continuous near-real-time multidisciplinary measurement series will extend over 25 years. Major research themes include: structure and seismic behavior of the ocean crust; dynamics of hot and cold fluids and gas hydrates in the upper ocean crust and overlying sediments; ocean/climate change and effects on ocean biota/fisheries at all depths; deep-sea sedimentation, ecosystem dynamics and biodiversity; and engineering and computational systems research. These involve interacting processes, long-term changes, and chaotic, episodic events difficult to study and quantify by traditional means.

The NEPTUNE, VENUS (Victoria Experimental Network Under the Sea), and MARS (Monterey Accelerated Research System) cabled observatories will use most of the same cable and engineering systems, with the latter two acting as shallow and deep-water test-beds, respectively, for the former. NEPTUNE is a Canada/US partnership with the total facility cost of about CAN\$250M. Over \$40M has already been funded for design, development and test beds. Funding (\$82.4M) for NEPTUNE Canada's installation of Stage I comes jointly from the Canada Foundation for Innovation and the BC Knowledge Development Fund. The NEPTUNE Canada team comprises 25 staff with others on contract.

Alcatel Submarine Networks is contracted to design, manufacture and install the 800 km network loop with 5-6 observatory nodes with full operations starting in late 2008. Formal agreements are being concluded for the development of the observing systems for approved community science experiments, while the internal development of a Data Management and Archiving System (DMAS) is progressing well beyond the interim version designed for VENUS. Other discussions deal with First Nations, fishers, and national security issues. Future opportunities for innovative science, education and outreach, and public policy contributions are profound. Current and future planning, management issues, and opportunities and implications for new ways of performing science are discussed. VENUS and Stage 1 of NEPTUNE will form a linked coastal/regional ocean observatory system, and be among the first of many such cabled ocean observatories to be deployed worldwide.

Selected applications include: a) new scientific knowledge and interpretations; b) developments of new technologies; c) renewable and non-renewable resource development; d) climate change driven by the oceans; e) hazard mitigation: earthquakes, tsunamis, storms, slope failures; f) sovereignty and security; g) port security and shipping; h) ocean management and policy formulation; and i) education, outreach and public information.

## I. NEPTUNE PROJECT: SCOPE AND ORGANIZATION

NEPTUNE (North-East Pacific Undersea Networked Experiments) will be an innovative network of many sub-sea observatories linked by about 3000 km of powered, electro-optic cables covering the Juan de Fuca Plate (200,000 sq km), North-east Pacific, with shore stations at

Port Alberni, British Columbia and probably Nedonna Beach, Oregon ([www.neptunecanada.ca](http://www.neptunecanada.ca), [www.orionprogram.org](http://www.orionprogram.org), [www.neptune.washington.edu](http://www.neptune.washington.edu)). Each observatory, or node, will host and power many scientific instruments on the surrounding seafloor, in boreholes in the seafloor, and buoyed through the water column. Remotely operated and autonomous vehicles will reside at depth, powered and recharged at observatories and directed from distant labs. Continuous near-real-time multidisciplinary measurement series will extend over 25 years.

Major research themes being addressed by NEPTUNE Canada include: structure and seismic behavior of the ocean crust; dynamics of hot and cold fluids and gas hydrates in the upper ocean crust and overlying sediments; ocean/climate change and effects on ocean biota/fisheries at all depths; deep-sea sedimentation, ecosystem dynamics and biodiversity; and engineering and computational systems research. These involve interacting processes, long term changes, and chaotic, episodic events that are difficult to study and quantify by traditional means.

The NEPTUNE Project is a bi-national science megaproject with an estimated total infrastructure installation cost of about \$250M and an anticipated annual operating cost of about \$20-25M. The University of Victoria (UVic), BC, leads the Canadian program with a consortium of 12 universities across Canada and participation by many federal research laboratories. The US program is funded by the National Science Foundation (NSF), which has established the ORION Project Office and the Ocean Observing Initiative (OOI). The Office will announce an Implementing Organization (IO) to manage the US NEPTUNE (Regional Cabled Observatory) installation and initial operation in March 2007. In 2004, UVic and NSF signed a Memorandum of Understanding (MOU) to cooperate in installing the NEPTUNE interoperable observatory network.

## II. FUNDING SUPPORT

NEPTUNE and the associated VENUS (Victoria Experimental Network Under the Sea) and MARS (Monterey Accelerated Research System) ocean observatories will use most of the same cable and similar engineering systems with the latter two also acting as shallow and deep-water test-beds, respectively, for the former. The VENUS coastal test bed ([www.venus.uvic.ca](http://www.venus.uvic.ca)) was funded at \$10.3M (all dollar amounts in the text are given in Canadian dollars unless specified as US\$) jointly by the Canada Foundation for Innovation and the BC Knowledge Development Fund (CFI/BCKDF) in 2002 and is led by UVic with Verena Tunnicliffe as Project Director. Its first line was installed in Saanich Inlet in February 2006 and the other line across the Strait of Georgia will be added in mid-2007 in waters less than 300 m. MARS ([www.mbari.org/mars/](http://www.mbari.org/mars/)) will be installed near the Monterey Canyon, California, at 900 m water depth and 50 km offshore in mid-2007 by the Monterey Bay Aquarium Research Institute (MBARI). NEPTUNE is a Canada/US (40:60) partnership with over \$40M already having been funded by US agencies (e.g., by NSF) for power and

communications design, development and the MARS test bed. Funding (\$62.4M; CFI/BCKDF) for NEPTUNE Canada's installation was announced in October 2003 and a further \$20M was provided in September 2006; with further grants of over \$4M and in-kind support of over \$16M, the total funding secured by NEPTUNE Canada approximates to \$100M. US funding has totaled about \$40M to date, with the major funding of \$336M/6 years for OOI now under consideration, possibly to start in Fiscal Year 2008. Herein, the Canadian portion of the NEPTUNE Facility is referred to as Stage I, with the US portion called Stage II.

VENUS and Stage I of NEPTUNE will form a linked coastal/regional ocean observatory system, and be among the first of many such cabled ocean observatories. In the US, the Ocean Observatories Initiative has been spawned by NSF, which established the ORION Project Office in 2004 and is proposing a US\$336M infrastructure budget to cover observatory installation costs for coastal, regional and global-buoy observatory facilities. This funding would come from the Major Research Facilities, Engineering and Construction (MREFC) account after approval by Congress, which is currently considering this proposal. These would be new resources, similar to the US\$116M just announced by NSF for the refit of the *Resolution* as part of the US commitment to the new Integrated Ocean Drilling Program (IODP). Other regional ocean observatories are being planned in Japan (DONET) and around Western Europe (ESONET). It is emphasized that we are entering a new age of wiring the oceans with the potential to have large-scale, interdisciplinary, interactive, real-time experiments.

## III. NEPTUNE CANADA DEVELOPMENTS: PLANNING AND INSTALLATION

NEPTUNE Canada is a consortium of 12 Canadian universities (Memorial, Dalhousie, Rimouski, Laval, UQAM, Toronto, Guelph, Waterloo, Manitoba, Simon Fraser, UBC, and Victoria), led by UVic. Under the terms of the CFI/BCKDF awards, UVic is required to both own and then operate the observatory for at least the first five years. UVic has provided new space for NEPTUNE Canada and VENUS to be co-located on campus. After receiving news of its funding in late 2003, NEPTUNE Canada has been developing rapidly and currently has a full-time staff of 25 with others under contract. It has recently made two major funding announcements: for the wet plant infrastructure and for the scientific instruments supporting the community science experiments. In October 2005, UVic signed a contract valued at nearly \$39M with Alcatel Submarine Networks (ASN; within Alcatel-Lucent) to design, manufacture and install the wet plant infrastructure (cable and nodes) for NEPTUNE Canada. Some subcontractors such as Texcel Technology, L3 MariPro, and Alcatel-Lucent Canada will be involved in portions of the work.

This installation (see map of cable route and node locations, Fig. 1) will involve an 800km cable loop from UVic's shore station at Port Alberni, purchased in 2004

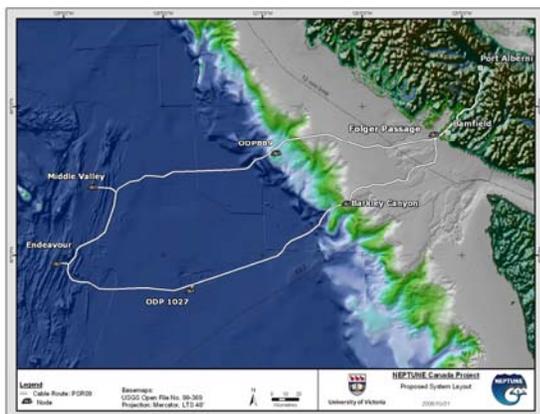


Fig. 1. Stage I, NEPTUNE map showing cable route, and node and shore station locations.

(Fig. 2), out to the Endeavour Ridge. Five instrumented observatory nodes (Fig. 3) will be located at 1) inshore Folger Passage, the slope sites of 2) ODP (Ocean Drilling Program) 889 and 3) Barkley Canyon, 4) the mid-plate ODP 1027 site, and 5) the ocean spreading site at Endeavour Ridge. A sixth node will be established at Middle Valley (sedimented portion of the Juan de Fuca Ridge) if further supplementary funding can be secured. At this point, a branching unit and spur cable will be installed at Middle Valley to allow later addition of the node and instruments. ASN manufactured the cable in Calais, France, and will install it and the Branching Units and spur cables in mid-2007 (July-August). The nodes are being manufactured by L3 MariPro in Santa Barbara, California, and most instruments will be deployed in mid-2008 after full testing and commissioning (Fig. 4). ASN also earlier won the contract to install the MARS observatory, with L3 MariPro as a subcontractor.

Technical details of the infrastructure are provided in the paper by Phibbs and Lentz in this SSC-07 Workshop proceedings volume.



Fig. 2 NEPTUNE Canada's shore station at Port Alberni



Fig. 3. ROV serviceable science node being lowered into trawl resistant frame (MARS node by L3 MariPro)

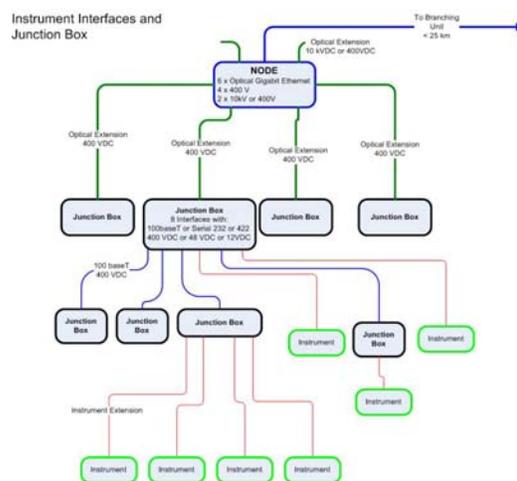


Fig. 4 Instrument Interfaces and Junction Box

#### IV. NEPTUNE CANADA DEVELOPMENTS: SCIENCE EXPERIMENTS AND INSTRUMENTATION

Brian Bornhold and Kim Juniper (initial Co-chief Scientists) have led the exhaustive analyses of the proposals and the required compromises; the details of the first \$7M awarded for instruments, extension cables, interface modules, and installation are listed in the October 2005 Newsletter at [www.neptunecanada.ca](http://www.neptunecanada.ca). With the supplementary \$20M, a further \$6M is being devoted to additional scientific instruments and connectivity costs. With the increased work to deal with about 175 instruments and over 700 sensors, NEPTUNE Canada appointed Dr. Mairi Best as Associate Director Science in late January 2007, with Brian Bornhold continuing as Project Scientist and Kim Juniper accepting a research chair at UVic. Many of the instruments will require

development work, followed by bench and wet testing prior to deployment, coordinated by Paul Hansen (Manager, Project Quality Assurance) and others using the Saanich Inlet VENUS node. Science workshops in mid-November 2006 further defined formal agreements for the acquisition, development and specifications for the instrumentation requested. We are also receiving further requests to add instruments by other scientists funded from other sources. The approved community science experiments, lead investigators, and the main instruments/sensors being deployed are summarized as follows.

#### A. Endeavour Segment of Juan de Fuca Ridge

##### 1) Monitoring Hydrothermal Systems

The Endeavour team will deploy instruments at two of the five vent fields on the Endeavour Segment of the Juan de Fuca Ridge – at the Main Endeavour Field and Mothra. Many of the instruments are those that have been used at the site in recent years by researchers from the University of Washington and will be modified to become network compatible. These include temperature-resistivity-hydrogen probes, microbial incubators and short-period seismometers.

At the Main Endeavour Field, temperature-resistivity probes, a microbial incubator, a high-resolution digital camera (or HDTV) and a McLane fluid sampler will be installed. At the Mothra Field, a temperature-resistivity probe, a microbial incubator, a McLane fluid sampler and a high-resolution digital camera will be deployed.

A regional circulation experiment, to characterize hydrothermally driven water mass movement, will set out four mooring arrays extending 250 m up into the water column. The instrumentation will consist of acoustic three-dimensional current meters situated at 10, 50, 125 and 250 m above the seafloor. With each current meter will be a sensor to measure temperature and salinity variations. One bottom pressure sensor will be deployed to accurately measure local tides.

University of Washington's existing short period seismometers at Endeavour Ridge will be refurbished and redeployed to continue the time series of seismic observations that have been ongoing for several years. As well a broadband seismometer will be deployed in the vicinity of the ridge to characterize the overall seismicity in the area in order to understand linkages between local tectonics and other biological and oceanographic phenomena being investigated by the Endeavour Ridge Monitoring Experiment.

A bottom pressure recorder (BPR) will be deployed near Endeavour Ridge as part of the tsunami monitoring network.

#### B. Barkley Canyon Region

##### 1) Hydrates

Various instruments will be deployed in the vicinity of the known outcropping gas hydrates along the northwest wall of Barkley Canyon in order to understand better the accretion and degradation of the hydrate mound structures as well as changes in biological and chemical activity in

the area. The sensors will include in situ temperature probes to depths of one metre or more, three rotary still cameras deployed near the known mounds and a "crawler" developed by the International University Bremen. The tracked crawler will carry a CTD, methane sensor, a Schlieren optical system, a webcam to control vehicle movements, a video system to quantify gas bubbles and possibly oxygen sensors or a benthic flow simulation chamber to study particle dynamics.

##### 2) Biophysical Linkages off Vancouver

The aim of the "water column" experiment is to develop a better understanding of the coupling between the physics and the biology off southwestern Vancouver Island and how this coupling relates to variability in oceanographic processes and responds to long-term climate change. The instrumentation will consist of a water column profiler, located in about 400 m water depth on the continental slope about 8 km to the north of Barkley Canyon. Profiles of water properties will be acquired through the entire water column. This profiler will be equipped with a CTD, oxygen sensor, fluorometer, transmissometer, nitrate sensor, carbon dioxide sensor, a multi-frequency acoustics package and an upwelling/downwelling radiometer. As well, bottom-mounted instruments will consist of an upward-looking 150 kHz ADCP and a pressure sensor.

##### 3) Role of Disturbance in Deep Sea Benthic Ecosystems

This benthic ecology experiment focuses on the region near Barkley Canyon and is designed to interface with the "water column" team working in the same area to examine changes in benthic communities related to the transfer of energy and nutrients from the water column to the seafloor, as well as through the canyon, in this highly productive area characterized by seasonal upwelling. Equipment will be deployed at four separate sites along the northwestern side of Barkley Canyon as well as within the axis; the latter is to investigate downslope transfer of sediments through the canyon. One instrument "pod" will be located near the vertical profiler to be installed by the water column research team.

Instrumentation will consist of acoustic current meters, sediment traps, rotary sonar systems, plankton pumps, video cameras, high-resolution still cameras, CTD with fluorometer, microbial metabolic sensor package and laser optical plankton counter. It is hoped that a hydrophone deployed in the vicinity of the canyon that will be able to detect slope failures in the area as well as marine mammals.

#### C. Folger Passage, Barkley Sound

##### 1) Physical and Biological Oceanography

The Folger Passage site is located near the entrance to Barkley Sound, about 10 km west of the Bamfield Marine Science Centre. The site will consist of two installations, one in about 95 m water depth and another near the summit of a rocky pinnacle in about 15 m water depth. The overall objectives of the scientific initiatives at this nearshore

location are to: identify the factors that control biological productivity, both within the water column and at the seafloor; evaluate the effects that marine processes have on fish and marine mammals; and to provide learning opportunities for students, researchers and the public.

The deep-water instrument package will consist of an ADCP (Acoustic Doppler Current Profiler), a multi-frequency bioacoustic sensor, an oxygen sensor, and a temperature/salinity sensor. A hydrophone will be installed at this location to detect and characterize marine mammals in the region. The pinnacle instruments will include a 3-D array of cameras to examine the response of rocky reef organisms to environmental variability, upward- and downward-looking high-frequency ADCPs and a light sensor. The Folger Passage site will be complementary to the water column site on the continental slope in about 400 m water depth where a vertical profiler will collect a variety of water property and biological data. Close proximity to the Bamfield Marine Science Centre will allow regional oceanographic information to be collected on a regular basis near the Folger Passage instrument arrays.

#### C. ODP Site 1027

##### 2) *Hydrologic Regime in Oceanic Crust, Tsunami Monitoring, Benthic Ecology, Seismicity*

At Site ODP 1027, on the abyssal plain in 2660 m water depth, the principal focus is on connecting the existing Ocean Drilling Program borehole monitoring systems to the observatory. Circulation obviation retrofit kits (CORKs) were instrumented at two holes in 1996 and an additional two holes in 2002; the holes extend tens to hundreds of metres into the igneous seafloor through a sediment cover of a few hundred metres. The objectives of this program are to monitor changes in crustal temperature and pressure particularly as they relate to events such as earthquakes, hydrothermal convection or regional plate strain. It is planned to connect two CORKs to NEPTUNE Stage I.

In addition, a triangular array of very sensitive bottom pressure recorders (BPRs) will be deployed in the area of ODP 1027 as part of the tsunami array that will include BPRs at most of the science locations. This array will extend 10 km on each side and will allow determination of open ocean tsunami amplitudes, propagation direction and speed. The NEPTUNE tsunami array will complement other information from buoy sensors and coastal tide gauges around the North Pacific, and contribute to our knowledge about how tsunamis (and similar large waves) behave, as well as providing real-time monitoring of the phenomena.

Nearby, at Baby Bare, a small outcrop of igneous seafloor, we plan to install a broadband seismometer with associated hydrophone and a single-point current meter. Close by, a benthic ecology program, consisting of high-resolution still cameras, rotary sidescan sonars, an ADCP and a CTD will be installed. Baby Bare is a site of slow fluid venting from the seafloor and, as such, may prove to be biologically of great interest located within this expanse of broad flat abyssal plain sediments.

#### D. ODP Site 889

##### 1) *Shallowly Buried Gas Hydrates on the Continental Slope*

Site ODP 889 is located on the continental slope in about 1250 m water depth in a well-studied area characterized by shallowly buried gas hydrates. Initially most instruments will be deployed in the Bull's Eye area and will consist of several suites of geophysical instruments, including a controlled source electromagnetic (CSEM) system and receiver, a seafloor compliance system (gravimeter) and a geophone array. The objectives of this investigation are to monitor changes in the hydrate distribution, depth, structure and properties, particularly in relation to earthquakes and regional plate motions. A broadband seismometer, and associated hydrophone and single-point current sensor will be also located nearby, as will a bottom pressure recorder as part of the tsunami array. At present no ODP boreholes in the area are equipped with CORKs; it is hoped that in the future, with the additional drilling that is planned for the area, CORKs can be installed and connected to the network can be installed to complement these other studies of gas hydrates and fluid fluxes on the continental margin.

#### E. Saanich Inlet

##### 1) *Science Support Test Bed*

It was recognized that many of the newly developed instruments would require rigorous field testing prior to long-term deployment on the deep ocean on the NEPTUNE observatory. As a result an award was made to establish and operate a test facility associated with the VENUS site in Saanich Inlet

## V. ROUTE SURVEYS

NEPTUNE Canada provided ASN with the necessary detailed route surveys for the cable/nodes. Cheryl Katnick (Manager, Permits and Rights of Way) has been compiling all available data along the 800 km route from many sources, especially from the University of Washington. Additional survey work has been necessary and much of this was accomplished in Fall 2005. The University of Washington's *R/V Thompson* was used for a month-long cruise to the Endeavour Ridge, led by John Delaney and Deborah Kelley. NEPTUNE Canada and NSF provided funding to ensure that the *Autonomous Benthic Explorer* (ABE/AUV, from WHOI (Woods Hole Oceanographic Institute)) was available to undertake systematic sea-bed mapping to facilitate the task of laying the cable along the narrow Endeavour rift valley and using the *Jason 2* remotely operated vehicle (ROV) for specific photographic imagery (including HDTV). Adien Aggenbach (cable routing consultant) was on board for part of the period as the NC route engineer. Aggenbach, Bornhold and Juniper participated on other vessels to complete two surveys across the shelf, including surveys with the ROPOS remotely operated vehicle and cone penetrometer tests, totaling over 1000km. A further ROPOS expedition is planned for August 2007 to survey the Endeavour instrument locations and recover seismometers for

interfacing to the network. A major effort is underway to convert all the survey data into GIS (Geographical Information System) format.

## VI. DATA MANAGEMENT AND ARCHIVE SYSTEM (DMAS)

NEPTUNE Canada has added new staff to develop the Data Management and Archive System (DMAS) and good progress has been made by the team led by Benoît Pirenne (Associate Director for Information Technology) on the interim DMAS for the VENUS project that is serving as a prototype for the needs of NEPTUNE Canada. We received about \$1M through the CANARIE Intelligent Infrastructure Program (CIIP), in partnership with IBM, to develop Web Services and to turn our software infrastructure into a Service-oriented Architecture (SOA) to control all the remote sensors from distant research labs. A parallel \$1M award to John Roston, McGill University, in partnership with NEPTUNE Canada and FlexMet Inc, developed software solutions for controlling the use and communication systems for high definition TV from deep ocean environments. A Preliminary Design Review for DMAS was conducted in June 2006 and a Critical Design Review is scheduled for March 2007.

New functionality to access imaging, acoustic and video data or navigate the observatory components will soon be released on the web site. As a technology demonstration, DMAS has also invested in MBARI's Automated Visual Event Detection (AVED) software, which will be adapted to automatically detect features in underwater video material, perform a classification and return results for inclusion as new metadata in our database. While AVED will be linked to DMAS through Web Services, it is anticipated that it will be run on GRID nodes outside of NEPTUNE Canada's direct IT infrastructure. A first implementation/adaptation of AVED should be installed within the next few months. Similarly, feature detection and classification in hydrophone data streams will soon be possible: The use of the Marsyas software developed under the leadership of Dr. Tzanetakis at the University of Victoria will be shortly made available through DMAS.

A recent DMAS "vision" workshop proposed a variety of practical examples of suggested software features, which include the ability to subscribe to data streams of selected sensors, the detection of user-specified events, the precise time-tagging of measurements, the ability to interact directly with instruments, to program instruments to react to scheduled or unscheduled activities, the ability to accurately report issues with instruments, to provide pre-processed data (e.g., hourly or daily averages), to provide a geographical interface (GIS) access to the data and to support links to other databases.

## VII. OTHER INTERACTIONS

In such a complex project, it is not unexpected that a wide variety of interactions need to be established. Regular meetings are held with First Nations councils and

representatives. Both the Canadian and US navies have operational interests in the area of the observatory array and a CyberSecurity Committee is working to ensure a balance between scientific objectives and national security interests. The shelf and upper continental slope areas within the observatory footprint is regularly fished by trawl and hook-and-line methods and we are endeavouring to limit the physical interactions between fishing gear and scientific instruments and infrastructure (cable, nodes); dialogue is occurring through a Fishery Advisory Committee. On scientific matters, NEPTUNE Canada management seeks guidance from its Science Advisory Committee.

## VIII. SUMMARY

The NEPTUNE Canada Project, building the Stage I of NEPTUNE, has advanced from a variety of planning and design efforts to allocating most of its \$80M budget for defined acquisitions and technological developments. The 800km cable installation will occur in mid-2007, with the five or six nodes and over 700 sensors deployed in mid-2008. The observatory array is expected to be fully operational in fall 2008. As US funding for the OOI has not yet been approved by Congress, Stages I and II of NEPTUNE will be installed at least four to five years apart. NEPTUNE Canada and its principal contractor, Alcatel Submarine Networks (within Alcatel-Lucant), and its subcontractors Texcel Technology and L3 MariPro, are playing a leading role in the advent of the new technologies for cabled ocean observatories that will transform the ocean sciences. Scientists or companies/institutions interested in joining the experiments or in adding instruments to the arrays are urged to contact NEPTUNE Canada (neptune@uvic.ca).

## ACKNOWLEDGEMENTS

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