Kanazawa, T., Sager, W.W., Escutia, C., et al., 2001
Proceedings of the Ocean Drilling Program, Initial Reports Volume 191

3. Borehole Seismological Observatory[1]

Shipboard Scientific Party[2]

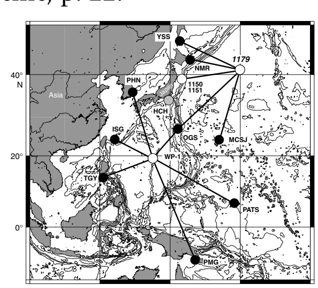
SYSTEM OVERVIEW

Purpose

A major limitation of our understanding of active tectonic processes largely comes from the fact that we lack in situ long-term observations in the oceans where many areas of major tectonic activity are found. Since the Deep Sea Drilling Project era, there have been many attempts to utilize boreholes for such purposes. For example, recent circulation obviation reentry kit (CORK) deployments to measure pressure and temperature changes in sealed boreholes are beginning to produce interesting results. The Ocean Drilling Program (ODP) continues to recognize the importance of long-term observatory objectives (ODP Long Range Plan, 1996).

Tomographic studies using earthquake waves propagating through the Earth's interior have revolutionized our understanding of mantle structure and dynamics. Perhaps the greatest problem facing seismologists who wish to improve such tomographic models is the uneven distribution of seismic stations, especially the lack of stations in large expanses of ocean such as the Pacific. The International Ocean Network (ION) project, an international consortium of seismologists, has identified gaps in the global seismic net and is attempting to install digital seismometers in those locations. One of the highest priorities of ION is to install a station beneath the deep seafloor of the northwest Pacific. A primary objective of Leg 191 was to install a permanent observatory at Site 1179, situated in the Northwestern Pacific basin (Fig. F1), which would become a long-term borehole seismological observatory. This section is surrounded by stations at Petropavlosk to the north, many

F1. Location map of seismic station coverage in the northwest Pacific, p. 22.



[1] Examples of how to reference the whole or part of this volume.
[2] Shipboard Scientific Party addresses.

Ms 191IR-103

Japanese stations to the west, Minami-Torishima Island station to the south, and the proposed Midway Island station to the east.

A global seismographic network was envisaged by the Federation of Digital Seismographic Networks to achieve homogeneous coverage of the Earth's surface with at least one station per 2000 km in the northwestern Pacific area. Thus, the Site 1179 seismic observatory will provide invaluable data, obtainable in no other fashion, for global seismology. Data from this observatory will help revolutionize studies of global earth structure and upper mantle dynamics by providing higher resolution of mantle and lithosphere structures in areas that are now poorly imaged. In addition, this observatory will provide data from the seaward side of the northwest Pacific trenches, giving greater accuracy and resolution of earthquake locations and source mechanisms.

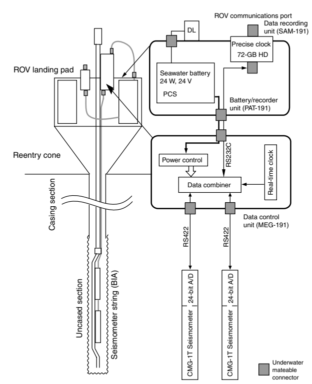
There are many bathymetric highs in the northwestern Pacific (e.g., Shatsky Rise and Hess Rise) whose roots are poorly known. Body-wave studies have not been able to determine the thickness of the plate; although large-scale anisotropy and lateral heterogeneity have been detected. Accumulation of broadband seismic data from within the basin part of the Pacific plate is needed to obtain detailed lithosphere and asthenosphere structure.

The northwestern Pacific borehole broadband seismic observatory WP-2 aims to provide seismic data to increase the resolution of tomographic studies.

NEREID-191 System Outline

We outline the NEREID-191 system of the borehole broadband seismic observatory WP-2 in this section (Fig. F2). The details of each component are described in separate sections. The observatory is designed to last for many years as a stand-alone system. Unlike other existing (Sites 1150 and 1151) and planned (proposed Site WP-1) oceanic borehole observatories, there are no nearby coaxial transoceanic telephone cables to utilize for data recovery and power. Therefore, the NEREID-191 installation is designed as a self-contained system with its own batteries and recorder. The two seismometers are designed to be placed near the bottom of the hole, each housed in a separate pressure vessel. Both sensors are feedback-type broadband seismometers (Guralp Systems Ltd., CMG-1T). Two separate cables are required to connect the sensors uphole. The signals are digitized in the sensor packages and sent in digital form to the seafloor packages.

F2. Schematic view of the NEREID-191 system of the WP-2 borehole seismological observatory, p. 23.



The seafloor package (MEG-191) (see Table T1 for abbreviations) serves to combine the digital data from the two seismometers to a single serial data stream. It also distributes power to the individual seismometers. The data are stored in digital format in a separate module (SAM-191) after being sent via an RS232C link using Guralp Compressed Format (GCF) protocol. The SAM-191 has four 18-GB SCSI hard disks capable of storing more than six channels of 1.5-yr-long continuous data of 24-bit dynamic range at 100-Hz sampling rate. In this case, there are three channels for each of the seismometers. The seismometers are emplaced in the borehole permanently; they are cemented into the hole as required to assure good coupling. The MEG-191, on the other hand, may be serviced by a remotely operated vehicle (ROV) or submersible. The MEG-191 can be physically replaced and accepts commands and software upgrades through the SAM-191. The SAM-191

T1. Glossary of the NEREID-191 system, p. 51.

must be replaced by an ROV or submersible before the hard disks become full, which is ~1.5 yr with the present design.

The SAM-191 also provides a communication link to the borehole system while the station is being serviced by the ROV or submersible. The SAM-191 can send part of the data to the surface across a serial link to check the health of the system. The SAM-191 measures the time difference between the clocks in the SAM-191 and MEG-191. Before deployment and after retrieval of the SAM-191, the time difference between the SAM-191 and the Global Positioning System (GPS) clocks is measured on board. Because the MEG-191 controls the timing of the whole borehole system, we can adjust the system timing to Universal Time Coordinated using the data from the SAM-191.

All the necessary power is supplied from the battery system, called the seawater battery (SWB). The SWB can supply up to ~24 W with >400 kWh capacity. Its energy comes from electrolytic dissolution of the magnesium anode, which needs to be replaced once it is consumed. The replacement is also designed to be handled by an ROV or submersible. The condition of the SWB system is monitored by the power control system (PCS), and data from the PCS are recorded in the data logger (DL). In addition, the PCS controls the power switch and will turn the switch off for the protection of the system under certain SWB conditions.

Environmental Requirements

Site 1179 is geographically situated in a large gap of the global seismic network (Fig. **F1**) where no seismic observatory exists within 1000 km. The seismic image of the Earth's structure beneath this area, especially in the upper mantle, is very ambiguous without a seismic station in this area. There are several requirements that must be fulfilled for the permanent installation of a seismic observatory so that the expansion of the global network to ocean is truly effective.

The seismic noise of an observatory should be as small as possible. The number of observed seismic phases depends on the magnitude of the seismic noise in the same frequency band as the seismic phases from earthquakes. Therefore, the reduction of seismic noise at the site directly enhances the value of the observatory. There are many sources of seismic noise. Environmental seismic noise caused by microseisms, infragravity waves, and water currents at the sea bottom are commonly recorded by ocean seafloor observatories. Each environmental seismic noise has a significant characteristic frequency band. In the frequency <0.1 Hz, seafloor seismic observations are significantly degraded by the noise caused by water currents at the seafloor. The magnitude of this type of noise can be higher than that of almost any long-period teleseismic phases. Escaping the flow noise by shallow burial of the seismometer in sediment or borehole installation was suggested and tried by several pilot experiments (e.g., Stephen et al., 1999). Because lower noise level is expected in a borehole rather than at the seafloor or in shallow sediment, especially long term, permanent seismic observatories should be installed in boreholes at the sea bottom.

Installation in a deep borehole seems to eliminate the effect of flow noise, but noises characteristic of borehole installation, such as turbulence in the water column of the borehole, might impair the advantage. For high-sensitivity measurements, pressure fluctuations that are the result of ocean long waves or temperature changes can be noise sources. Any water motion near the sensor is also a potential noise source. The seismometers must be grouted inside the borehole to avoid noise from water motion and to be optimally coupled to the surrounding rocks.

From the experience of Leg 186, during which borehole geophysical observatories were installed on the inner slope of the Japan Trench, it was determined that the infragravity wave was the dominant noise source with frequencies between 0.004 and 0.02 Hz. Using theoretical estimation, it is found that the acceleration of the ground as a result of tilt by the infragravity wave becomes maximum in a sediment layer; however, it becomes quickly negligible below the top of the basement. This is because the sediment has a large V_P/V_S ratio and horizontal shear stress takes a maximum value at a depth of the sensors. As a result, this factor leads to a large horizontal deformation of the sediment, giving rise to large tilts. Horizontal traction is maximum at the bottom of the sediment layers, whereas the vertical traction is maximum at the seafloor, a consequence of the traction-free boundary condition at the seafloor. The depth of the horizontal traction maximum is mostly determined by the wavelength of the applied pressure signal at the seafloor, although shear strength is also an important parameter. The wavelength of infragravity waves is more than a few kilometers in the frequencies of interest. Consequently, the horizontal stress takes a maximum value at the bottom of the sediment column unless the sediment thickness is extreme. Therefore, a seismometer in deep sediment cannot avoid suffering large horizontal infragravity wave noise, whereas the vertical noise level is improved the deeper the installation depth goes.

It is necessary to install a seismometer in igneous basement, rather than in sediment, to reduce the noise caused by infragravity waves. Because the seismic noise from infragravity waves in the horizontal component is smaller by >40 dB in basement, it is very important to install a borehole seismometer in basement.

INSTALLATION TECHNIQUES

Requirements

To obtain high-quality data, a suitable instrument, as described in **"Borehole Instruments,"** p. 6, must be in intimate contact with the host rock. This is accomplished by cementing robust instruments in the bottom of an open hole in competent, indurated rock. At Site 1179, we planned to install and cement the seismic instruments within basaltic basement.

One of the complications of subseabottom installations arises from having to cope with irreducible ship heave during hole entry. Because heave may be a meter or more, cables linking the instruments with the seafloor data handling units have to be protected from stresses arising out of relative motion between the units and the hole wall and between the units and any insertion tools. Although the passive and active heave compensators can be used during hole entry, the instrument string has to hang from the rig floor without compensation while pipe is being added. Pipe is added every 10 to 30 m for ~475 m of hole penetration. In addition, for the cement to set properly, the instrument package has to be completely undisturbed for about a day after the cement is introduced.

Methods

The technique we have developed to satisfy the installation requirements listed above is illustrated in Figure F3. The instrument package is supported on 4.5-in diameter casing pipe that hangs on the base of the reentry cone at the seafloor. This has two advantages: (1) the pipe provides a conduit for cement pumping and (2) it also keeps the package stationary once its support (riser/casing hanger) lands on the hanger at the base of the cone. After cementing, the drill pipe from the ship can be uncoupled and withdrawn, leaving the casing pipe in the hole. The cables are protected by strapping them to the casing pipe and are also protected from wall contact by centralizers (Fig. F4). Therefore, there is no motion between the cables and the support tube (casing pipe) and no contact with the borehole walls. Strapping the cables to the support tube minimizes the tension in the cables. Armored cables are not required, and the cable structure is such that it is almost neutrally buoyant in seawater, further minimizing long-term stress on the cables.

It has been found that cement pumped through a pipe into a water-filled hole does not penetrate much below the pipe opening, tending rather to force its way upward. To make a strong plug below the seismometers, a 3.2-m-long extension tube called a stinger is coupled to the bottom of the borehole instrument assembly (BIA) that supports the seismometers. This ensures that the seismometers are sealed off from the bottom of the hole and that a strong cement plug extends well below the lower seismometers.

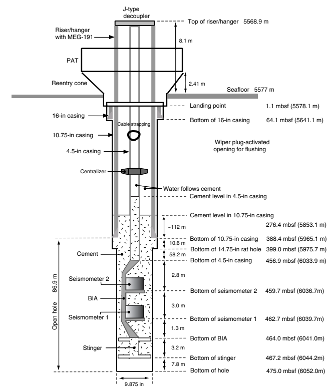
The cement is pumped through the casing pipe, the BIA, the stinger, and then up around the BIA into the 10.75-in casing. In Hole 1179E, the open hole was 86.9 m, the top end of the stinger was 11 m above the bottom of the hole, and cement was pumped up from the bottom of the stinger, filling ~198.9 m of the hole (Fig. F3).

To avoid water circulation in the borehole column, which may cause seismic noise, the entire hole should be filled with cement. However, a long column of cement makes an overpressure at the position of the seismometers because of the cement density of ~2.0 g/cm^3. The cables from seismometers may be damaged by the overpressure because a pressure limitation of the borehole cables is ~6500 m. Therefore, we adopted a length of ~200 m for the cement fill, a compromise between filling the hole and limiting the overpressure.

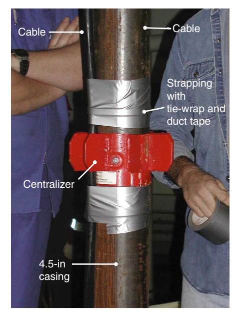
Figure F5 shows the BIA. Each of the two sensors has its own cable to the seafloor unit. There are a number of reasons why this plan was adopted rather than having a single armored cable carrying all the signals. Because we do not know the exact depth of installation until the hole has been drilled and the formation evaluated, the downhole cable cannot be cut and terminated ahead of time. Cable termination with an underwater mateable connector (UMC) is a delicate operation and took ~16 hr for the two connectors used during Leg 191. With flexible cable, enough slack can be provided that errors in the termination length can be tolerated. With armored cable, this would be impossible and the termination would be extremely difficult to accomplish onboard ship.

An overriding concern has been the long life of the installation. A 10-yr goal is necessary if we are to achieve all the scientific objectives. Our experience with long-term land installations is that cable leakage and electronic component failure are the most likely sources of data termination. For this reason, we use multiple cables and much of the electronic circuitry is contained in a removable seafloor unit, as described in "Seafloor Instruments," p. 9.

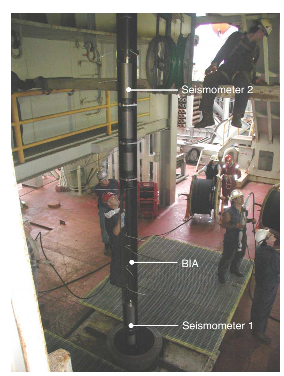
F3. Borehole instrumentation assembly installation schematic, p. 24.



F4. Cable strappings and centralizer, p. 25.



F5. Borehole instrumentation assembly placement, p. 26.



Borehole Instrument Assembly

The BIA is designed to prevent the instruments from being damaged during the installation in the borehole and to secure a conduit for cement pumping. The main frame of the BIA is a 0.076-m-diameter × 7.1-m-long steel pipe with two blades, which have an angle of 62° between them (Figs. F6, F7, F8, F9). The steel pipe serves as a conduit for cement. The 5.5-m-long middle part of the pipe is shifted toward outside so that two ocean borehole seismometer (OBH) sensors (S/N T1036 and T1037) and their cables can be emplaced there. Two OBH sensors are situated and fixed on the frame pipe in the area between two blades. The two blades protect the instruments from being hit and abraded by the hole. The surface of the frame pipe, where the pressure vessels of the OBH sensors touch, is covered with fiberglass cloths to insulate the instruments from the frame pipe (Figs. F10, F11). A 3.2-m-long stinger pipe with centralizers is bolted onto the bottom of the BIA. Cement that is pumped into the hose flows through the drill pipes, the BIA frame pipe, and the stinger. At the last moment, cement floods out from the lower end of stinger and rises upward to fill the space between the instruments and the borehole.

BOREHOLE INSTRUMENTS

Ocean Borehole Seismometer

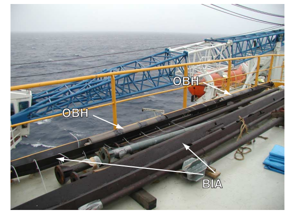
The OBH package consists of a three-component seismometer and a 24-bit digitizer (DM24) assembled in a grade five titanium pressure cylinder 1.2 m long × 12.7 cm outside diameter (OD). The cylinder is designed to withstand pressures at 10,000 m water depth, and all of the cylinders were tested at a pressure of 72 MPa. The two seismometers are model CMG-1T units made by Guralp Systems, Ltd. Each consists of three orthogonal sensors stacked vertically in the canister with a vertical sensor above two horizontal sensors (Fig. F12). Two OBHs were mounted on a BIA frame lengthwise with 3-m spacing.

Mechanically, the vertical OBH sensors are of the Ewing type and the horizontal sensors are of an inverted pendulum type. Mechanical details of the vertical sensor are shown in Figure F13. The inertial mass is a boom supporting a transducer coil. The boom consists of a solid machined beam. The vertical sensor mass is supported by a prestressed triangular spring to compensate for its weight and has a natural period of ~0.5 s. The horizontal sensor mass is centered by an unstressed flat triangular spring and has a natural period of ~1 s. The effective mass of each sensor is ~250 g. The springs are connected to the frames with a temperature compensating thread that minimizes the effect of temperature variation. A compact design is achieved chiefly by the short stiff springs and short boom.

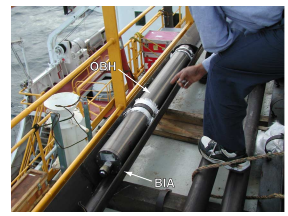
The adjustments required for operation consist of leveling the boom of the vertical sensor and tilting the bases of the horizontal sensors to center the mass movements in their equilibrium positions. Adjustments are made by small (1 cm diameter × 3 cm long) direct current (DC) motors operating gear mechanisms to tilt the bases of the horizontal sensors and to apply a small extra force to the vertical sensor's boom.

Before and during borehole installation, the instrument may be subjected to severe motion that can damage the mass support hinges. Consequently, the masses have to be locked securely in their frames and the

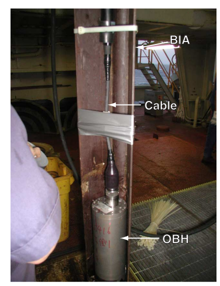
F6. Appearance of the borehole instrumentation assembly, p. 27.



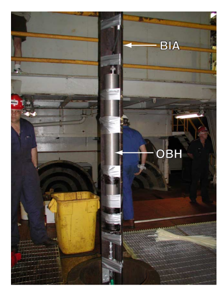
F7. An OBH sensor emplaced on the borehole instrument assembly, p. 28.



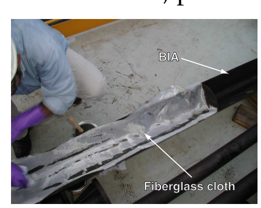
F8. Cable connections to the OBH during BIA installation, p. 29.



F9. Installation of the BIA in the moonpool area, p. 30.



F10. Insulation between the OBH sensors and the BIA, p. 31.



hinges released. This operation is performed by a small motor-driven clamp, which is controlled by a command to the DM24 digitizer.

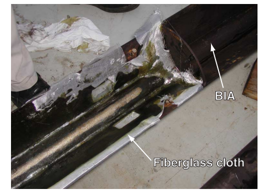
The sensors employ feedback to expand their bandwidth and dynamic range. The response of the sensor is determined by the characteristics of the feedback loop. The mass position is sensed by a capacitative position sensor. The voltage from the sensor, which is proportional to the displacement of the mass from its equilibrium position, is amplified and fed to a coil on the mass. The current in the coil forces the mass to its equilibrium position. With a high loop gain, motion of the mass is essentially prevented and the feedback voltage is then a measure of the force, and thus the acceleration, applied to the mass.

Block diagrams of the feedback system are shown in Figure **F14**. In order to obtain stable performance over the whole frequency range, the feedback-loop phase shift has to be carefully controlled by compensation components in the forward and feedback paths in the system. There are two feedback paths; one consists of a single capacitor in parallel with a resistor, and the other consists of a noninverting integrator in series with a resistor. The arrangement gives a double pole at specific frequencies. The system velocity responses are defined by a transfer function identical to that of a conventional long-period sensor with a velocity transducer whose natural resonance period is set at 360 s with the damping factor at 0.707. The velocity output (flat to 100 Hz) is fed through a low-pass filter (<50 Hz) before the digitizer. The mass position output can be used for periods >360 s. The short period performance of the Leg 191 seismometer was improved over the one deployed during Leg 186 by an improved displacement transducer circuit. Figure **F15** illustrates the instrument self-noise curves for vertical and horizontal components of the OBHs in comparison to those from Leg 186. The OBH for Leg 191 is >10 dB quieter at frequencies >2 Hz than the one deployed during Leg 186.

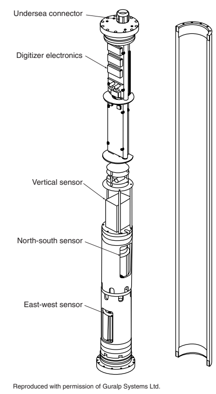
The output signals, such as velocity and mass position, are digitized by the DM24 digitizer. A detailed description of the DM24 digitizing module is given later in this section. The velocity outputs are digitized at 100 samples per second (sps), and the mass position outputs are digitized at 4 sps. The digitizer was programmed to produce decimated optional velocity outputs at 20 sps, although the sampling frequencies of velocity channels can be changed by commands. The sensitivities are ~2.4×10^{-10} m/s/bit for the velocity outputs and 8.0×10^{-8} m/s^2/bit for the mass position outputs. The DM24 also digitizes the signal from a temperature sensor in the OBH cylinder at a resolution of 12.87 mK/bit. All the digital data are sent to the MEG-191 seafloor data module through a 450-m-long cable. The communication link to the MEG-191 is a four-wire 38,400-bps (bits per second) RS422 serial link. As well as sending the signal data, the DM24 receives the time reference signal from the MEG-191 and synchronizes the OBH clock to the MEG-191 clock. The precision of the OBH synchronization is typically within 200 µs. The OBH clock is resynchronized to the reference if the time offset between the OBH and the MEG-191 clocks becomes >20 ms. The OBH clock in the DM24 records the time in the digitized records.

The voltage range for the OBH is 10–36 V. Because the 450-m-long cable resistance is ~11 Ω, the supply voltage can be varied in response to the power consumption of the OBH instrument. A large power consumption is required when the sensor mass unlock/lock is performed. This large current in the power line may cause damage to the DM24 processor. Therefore, an electrolytic capacitor with 4700 µF of capacitance and 63 V of resisting voltage is employed to eliminate undesirable

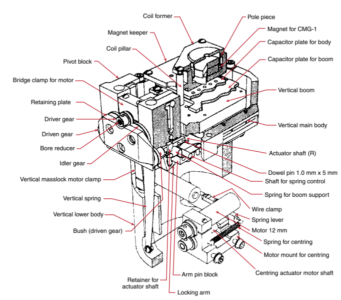
F11. Fiberglass cloth glued over the surfaces of the BIA, p. 32.



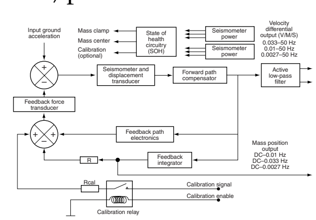
F12. Components of the ocean borehole seismometer used for Leg 191 installation, p. 33.



F13. Drawing of the CMG-1T vertical sensor, p. 34.



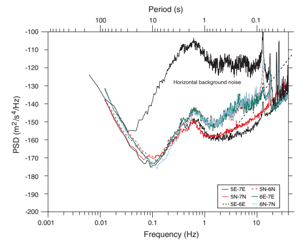
F14. Schematic diagram for the electronic circuits of the CMG-1T sensors, p. 35.



effects caused by voltage fluctuation. A 100-Ω resistor is connected serially with the capacitor to limit the charging current of the capacitor. The limitation of current in the power line is important to protect the power supply. A diode is also connected to the resistor in parallel for discharge of the capacitor. The capacitor must discharge quickly when power is turned off. The 450-m cable that contains both the power supply and the data link is connected to the OBH by an eight-way underwater connector (SEACON MSSK-8-BCR) attached to the top bulkhead. The power consumption of the OBH instrument is ~2.5 W during regular operation of the sensor. Power loss in the long cable is expected to be ~0.15 W. The OBH power is supplied through a DC/DC converter in the MEG-191 to isolate the power ground from that in the MEG-191, and its efficiency is ~80%. The overall power consumption of the OBH is ~3.3 W during normal operation. When the masses are locked, each OBH consumes 0.2 W more power.

The microprocessor in the DM24 controls various functions of the sensors such as unlocking/locking the masses and bases of the horizontal sensors and centering the masses. These controls are initiated by a command sent from the MEG-191 or automatically by the program in the OBH system. The OBH system is programmed to start unlocking the sensors and centering the masses after a programmed date, which must be set after the deployment. During Leg 191, this date was set to 15 September 2000 for all sensors. Another task related to control of the sensor is auto centering. The masses are recentered whenever they deviate from the center position by a more than half of the range of the mass movement.

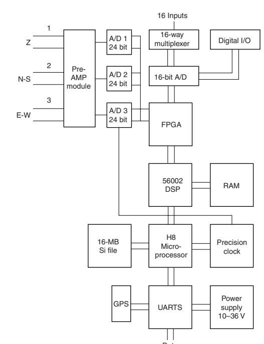
F15. Spectra of instrument self noise for horizontal components of the OBHs, p. 36.



DM24

The DM24 is a modular intelligent digitizer developed by Guralp Systems, Ltd. The schematic diagram of the DM24 is shown in Figure **F16.** Each DM24 has three single-ended analog input channels to 24-bit analog to digital (A/D) converters as well as additional eight-component 16-bit A/D channels. Each DM24 consists of rectangular printed circuit boards in the OBH. The 24-bit digitizer utilizes the Crystal Semiconductor CS5321/2 chipset and Motorola 56002 Digital Signal Processor (DSP). The CS5321/2 digitizes signal at 2000 sps, and the data are processed by the 56002 DSP to give lower sample-rate data. The high sample-rate data are filtered and decimated in four cascaded stages. The first stage decimates the data by 10 to give 200 sps. The following three stages can have various individual decimation factors that allow multiple data output rates to be selected simultaneously. Sampling by the CS5321/2 is triggered by an Hitachi H8 16-bit microprocessor. The H8 processor receives data from the DSP, buffers it in 512 KB of S-RAM memory, and sends it through the serial link outside the module in GCF (see **"Guralp Compressed Format,"** p. 9, in "Seafloor Instruments"). Transmission of the data by the processor is intelligent so that even a lost packet during transmission can be recovered by handshaking upstream in a block recovery protocol.

F16. Schematic diagram of the DM24 digitizer, p. 37.

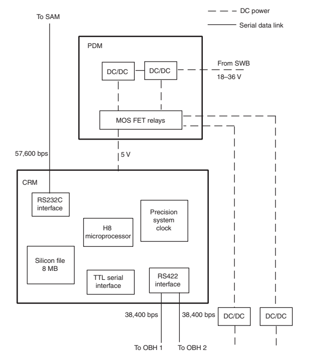


SEAFLOOR INSTRUMENTS

MEG-191

The multiple-access expandable gateway (MEG-191) is composed of a combiner/repeater module (CRM) and power conditioning/distribution module (PDM) (Fig. F17). The major role of the MEG-191 is to acquire signals from each sensor and send out the converted digital data to the SAM-191 data recorder across a single serial link.

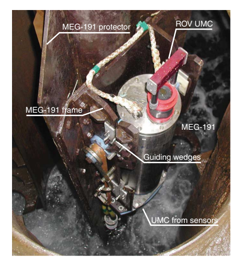
F17. MEG-191 system block diagram, p. 38.



Mechanical Design of the MEG Frame

Within the MEG-191, all of the electrical components are stored in an 8.5-in OD titanium pressure vessel (Fig. F18). The vessel is sealed at the top and bottom by bulkheads. On the top bulkhead, a UMC from Ocean Design, Inc. is installed. The UMC, which has four conductor pins, is an interface to the SAM-191 and the SWB and is joined by a 20-ft-long ROV cable to the power access terminal (PAT), in which the SWB and SAM-191 are stored. On the bottom bulkhead, four titanium UMCs are installed and connected to the long cables that connect the seismometers to the seafloor electronics. The UMCs at the bottom of the MEG-191 connect each OBH at the bottom of the borehole to the MEG-191. The UMC on the top bulkhead has a latch mechanism, whereas the bottom UMCs are stab-mating connectors that require continuous stabbing force to maintain connection. The required stabbing force is 36.4 kg total for the four connectors, which is provided by the weight of the MEG pressure vessel (70.9 kg in air; 37.3 kg in water without contents). The vessel is inserted to a MEG frame (Fig. F18) that connects electrically with the downhole seismometers. The MEG frame is part of the riser/hanger assembly that stands up in the center of the reentry cone. The MEG frame holds the vessel and aligns the bottom bulkhead connectors to the UMC receptacles on the stab plate, which is at the bottom of the frame. The MEG pressure vessel can be removed from the frame. The bottom UMC connections can be disengaged safely by operating a handle attached to the MEG frame. At the bottom of the frame, a set of levers with a latch mechanism is linked to the handle to push the vessel out. After UMC disconnection, the vessel can be pulled out of the frame with a rope. Thus, the MEG-191 may be replaced even after being deployed on the seafloor. The retrieval of the MEG-191 may be necessary if it malfunctions.

F18. Photograph showing the MEG-191 installed in the MEG frame, p. 39.



To guide the vessel correctly into the MEG frame, four 0.010-mm-diameter titanium pins are attached to the sides of the vessel. Two pins are at the top and two are at the bottom. The pins slide into the slots of the MEG frame and define the orientation of the vessel, which allows the UMCs at the bottom of the vessel to mate smoothly upon insertion. There are also two plastic wedges on the top side of the vessel, which together with wedges on the MEG frame, are designed to increase the space between the vessel and the frame side members. This allows the vessel to be easily reinserted into the frame if replacement by an ROV is necessary. The MEG pressure vessel is electrically isolated from the frame to prevent galvanic corrosion.

Guralp Compressed Format

GCF is a format that allows many different time-series data channels to share a single transmission line. The format is used to transfer data throughout the NEREID-191 system. It can also transfer status messages in ASCII characters. Each GCF-format data transmission is an information packet containing either a data block or a status block. The GCF packet consists of an identification character (G), transmission serial ID, data/status block contents, and 2-byte checksum characters. The transmission serial ID increments by one for every packet. The serial number enables the receiver to recognize a lost GCF packet and will result in a request for the lost packet to be resent. The data block is used for time-series data transfer, and the status block is used for the sensor status information. Each data block stores data in multiples of a full second, starting on an exact second. The data block consists of a header and compressed data. In the 16-byte header, the most basic attributes of the data are stored, such as system ID, stream ID, date and time of the observation data, number of sps, number of data in the block, and type of compression in the data block that follows. The set containing system ID and stream ID identifies the source of the data. The assignments of the system ID/stream ID by each source are listed in Table T2. Simple data compression is done by the first and last complete values in each block and the difference values between adjacent samples. The bit lengths of the difference values are all the same in a data block and are 8, 16, or 32 bits, depending on the maximum first difference in the signal in that data block. The status block has the same header as that of data blocks, but its sps field is set to zero and the compression byte has a value of four. After the header, status information in ASCII characters follows. The status block transfers many different types of information, such as boot messages, progress reports of seismometer mass control, and measurements of clock offset between the CRM and the DM24s.

T2. Mapping between sensor channels and stream ID in GCF, p. 52.

Each DM24 has a clock that adds time information to the data sent to the CRM. These clocks are independent from the precision clock in the CRM, which is the reference. The DM24 clocks have less accuracy; therefore, the clocks in the DM24s must always be synchronized to the accurate clock in the CRM. Each DM24 receives the time reference signal and adjusts its clock oscillator to synchronize with the reference. The adjustment to the external clock can be performed by either GPS or stream-sync time base signal; however, all the DM24 clocks in the MEG-191 and OBHs are set up to use the stream sync. The stream-sync signal is a set of clock synchronization characters sent by an upstream module through the serial data link to the DM24. The signal consists of 2-byte characters sent every second; date and time information is transmitted over 1 min. The first character (0x10) of each 2-byte character represents the timing reference, which is accurately synchronized to each second of the clock in the transmitter. The second character represents a part of a date or time. Although the first character is synchronized to the second, the processor actually needs the second character to compare with its own clock. Therefore, the receiver's internal clock will be delayed for the little time it takes to send the 10-bit data in the serial data link (~0.2 ms in a 38,400-bps line). The difference between the clocks is measured every minute. The adjustment of the clock oscillator is also performed every minute. The time difference between the clocks is typically kept within 200 µs. When the difference between the clocks becomes >20 ms, the DM24 clock is resynchronized to the standard in the CRM. The DM24s report the time difference in a unit of 25/1536 µs in the GCF status block.

The DM24 can be interactively configured or commanded through the same serial link that is used for data transmission. With a simple command line, control of the sensor attached to the DM24 in the

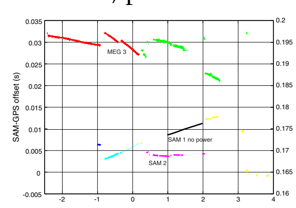
DM24 is possible (e.g., mass unlock/lock, mass centering). The system programs are customized to fit the sensor attached to the DM24. As well as the control on demand of a command from outside, some of the DM24s can have a task that automates the control of the sensors. For example, the DM24 for the CMG-1T seismometer has a process to monitor the mass positions and centers the masses when they deviate by more than half of the full scale from the zero position.

Combiner/Repeater Module

The CRM collects digital data from all the DM24s in the OBHs. The serial link between the CRM and the DM24 in the MEG-191 is a transistor-transistor-logic (TTL) level interface to minimize power consumption in its line driver/receivers. An RS422 serial interface is used to connect the CRM to the OBH to ensure a link of sufficient quality over a cable length of 450 m. The serial links from the CRM to the DM24s in the OBHs are optically isolated. The downhole power lines are also isolated with DC/DC converters. Complete electrical isolation of each component is necessary to avoid corrosion in case of an accidental electrical leakage to seawater. The data collected by these serial interfaces are handled by an Hitachi H8 microprocessor. The data are buffered in an 8-MB silicon file in order and are transmitted to the SAM-191 recorder through a high-speed 57,600-bps RS232C serial interface.

The H8 processor controls a precision reference real-time clock (RTC) in the same manner as the DM24. The reference RTC is a temperature-compensated precision clock, and the trimming of the oscillator by the processor makes its accuracy better than 1 × 10^{-8} (Fig. **F19**).

F19. Example showing the results of the time difference measurement between the MEG-191 and the SAM-191, p. 40.



When the ROV plug from the battery frame is connected to the MEG-191, the CRM boots the whole system upon system power up. The CRM runs a boot loader in its EPROM first, and the boot loader reads the actual program from EEPROM in its CMOS memory to run the system. The CRM will also allow the system program to be loaded from the high-speed serial data link. After the system program is started, the CRM begins to handle data transmission and powers up all the seismometers sequentially. The CRM in the MEG-191 executes the command at the time-determined running state, whose number increases every minute from boot time. The CRM controls all the power for itself and the OBH. All of the supplied current for the OBHs connected to the MEG-191 is monitored by the CRM every minute. If the average current for the OBH over 1 min exceeds the preset limit (160 mA), the CRM in the MEG-191 shuts down the power of the OBH with overcurrent and will not automatically power on the OBH for the protection of the power supply circuit. The MEG-191 also checks the hourly supplied voltage average from the SWB. If the average voltage over two successive hours falls below the threshold (23.05 V), the CRM in the MEG-191 shuts off one of the OBHs to conserve power consumption. The CRM confirms that the SWB has little power using two successive measurements of the voltage from the SWB. Because the storage acquisition module (SAM-191) needs a large current for writing data to the disk, there is a possibility that the voltage of the SWB can drop temporarily. Writing data to the disk typically takes ~35 min. When the voltage of the SWB is greater than threshold over 2 hr (e.g., the CRM obtains two successive measurements of an average voltage above the threshold) after shutting down one OBH, the CRM in the MEG-191 switches on the OBH that had been shut down. When the CRM in the MEG-191 finds that the hourly average voltage is smaller than the low threshold (21.47

V), the MEG-191 and the OBHs will be completely shut off for 24 hr. After 24 hr, the CRM will try to boot again.

The CRM produces a GCF status message every minute to report the condition of each system. The status message is composed using ASCII strings (Table T3) and reports the status of power distribution, clock synchronization, and intersystem communication. The status message from the CRM in the MEG-191 contains ~400 bytes and the CRM in the SAM-191 contains an additional ~100 bytes of information about the data buffer status.

T3. Explanation of status messages from the CRM in the MEG/SAM, p. 53.

When the CRM in the MEG-191 receives a set of characters to request a command session from the upstream SAM-191, it stops sending data and switches to command session mode. In command session mode, the CRM provides features to control many other modules, such as the master RTC or the PDM, in a simple command set. The available commands (those of the DM24s, SAM-191, and CRM) are summarized in Table T4. The command session is finished by a close command from upstream or by a timeout of 1 min. The command session can be established between a DM24 and upstream modules over the CRM through the high-speed link, in what is called a pass-through. When an upstream unit requests the CRM for a connection to a DM24, the CRM stops sending data to the unit and relays the connection request to the DM24. The CRM continues to maintain the command session link until the upstream unit finishes the session.

T4. Available command set in the CRM, OBH, and SAM, p. 54.

The watch-dog fail-safe timer, which is a part of the H8 microprocessor reset circuit, is employed to reset the CRM. The timer needs to be triggered at least every 1.5 s. The CRM system multitasker normally does this every second. If there is some failure of the CRM program, a failure to trigger the timer results in a system reboot.

Power Distribution Module

The PDM is a unit that switches and distributes power to all the sensors and the CRM. The PDM measures the supply voltage and currents and sends that information to the CRM. The PDM can have a maximum of seven channels of power switches independently controlled by the CRM. The CRM in the MEG-191 utilizes two channels for the OBHs; the CRM in the SAM-191 uses three channels for hard-disk units.

Each power channel is switched by separate MOS FET (LH1517) relays. Channels 1 and 2 are different from the others in that they employ two LH1517s to double the switchable load. Current through each power channel is monitored by the CRM every second. To protect other modules, the CRM shuts down a channel if it draws an unexpectedly large average current over 1 min. Shutdown criteria can be different for each component and are configured in the CRM system CMOS memory.

The PDM controls power to the CRM, which controls power to the sensors. This is done by the power management circuit along with a battery backup RTC, which can run on a very small power supply. The PDM monitors the SWB voltage, and if the voltage drops to <17.5 V, the PDM switches off the CRM (and thus all the sensors) to prevent the system from running into an unstable condition. If this situation should occur, the system is kept down until the voltage is restored to ≥25.0 V or for 24 hr. This temporary shutdown will ensure that the SWB battery will recover its normal operation. Within this shutdown period of 24 hr, the system can be restarted by cycling power for 2 min until the PDM automatically shuts the system back off. If there is the need to operate the system intentionally under this situation, we can change the status of the system by sending a manual command to the normal sequence of operation. The PDM can also be configured to power the system on a preset date with a wake-up command.

Downhole Link

Two 450-m-long cables, which are tied to the 4.5-in casing pipes, supply power for each downhole OBH as well as transfer data for the MEG-191. The cables have eight conductors each. Each of the long cables is branched to terminate with two 4-conductor female UMCs 1 m below the connectors. Two UMCs for each OBH were necessary because there were no UMCs with more than four conductors that can withstand 6000-m-depth pressures. The OD of all cables is 0.0195 m. The structure of the cable from the center is two layers of conductors covered with an inner jacket made from high-density plastic elastomer (HDPE) and a tension member made of aramyd fibers covered with an HDPE outer jacket. The fiber tension member provides good tensional protection of conductors up to 1800 kgf (N) of maximum tensional load. These cables retain enough mechanical flexibility to allow a bending radius as small as 12 in. The cables are designed to have a low specific gravity (1.05 g/cm^3) in seawater. Thus, these cables experience minimal tension in the borehole. They are also strapped to the 4.5-in casing at 1.5-m intervals with centralizers. The cross-sectional area of the conductors is 1.25 mm^2. The cable resistance for a 700-m length is 11.3 Ω.

The cable for the OBH consists of three DC power supply wires (two negative and one positive), four data transmission line wires, and one signal ground. The electrical characteristics of the data transmission line conform to RS422 serial communication standards. The digitized seismic signal and the seismometer status are transmitted through the uplink in GCF format. The acknowledge characters for the uplink data and clock synchronization signal are sent by the CRM to the MEG-191 through the downlink. Commands to control the seismometer, which may be issued manually during ROV operations, can also be sent through the downlink. The GCF acknowledge characters, the clock synchronization characters, and the command characters have different formats so that the seismometer can distinguish them.

The assignment of the cable wires, as well as the pin assignment of connector pins on both the MEG-191 UMC and the sensors, is summarized in Table T5.

T5. Pin assignments of underwater mateable stab plate connectors, p. 56.

SAM-191

The SAM-191 is the recorder that is mounted on a frame located on top of the PAT battery frame. The SAM-191 is connected through an ROV-operated cable to the MEG-191. When the SAM-191 storage becomes full after ~1.5 yr of recording, an ROV can replace it with an empty SAM-191. Ejection of the SAM-191 is facilitated by a lever mechanism on the frame.

The power to the SAM-191 is supplied in parallel with power to the MEG-191 directly from the SWB, with a typical voltage of 27 V. The SAM-191 receives data from the MEG-191 through a high-speed (57,600 bps) RS232C serial link. The four-pin stab-mating UMC at the bottom of the SAM-191 cylinder connects the SWB power supply and data link for the MEG-191. The SAM-191 buffers the received data in a silicon file that consists of 64 MB of flash memory. The flash file is nonvolatile memory so that data will not be lost even during power loss. When 56 MB of data is written, flushing of the buffered memory into a hard disk drive (HDD) is initiated. The amount of data incoming to the SAM-191 is expected to be ~15 kilobits per second in a standard recording configuration, as summarized in Table T6.

T6. Data storage estimation for the seismic observatory, p. 57.

The SAM-191 has four SCSI 3.5-in 18-GB HDDs, which makes a total of 72 GB of storage. The HDDs are powered only on the memory flush, and only one disk drive is activated to spin up, while the other HDDs are kept in standby mode. The speed of data transfer is ~1.56 MB/min. Thus, it takes ~35 min to flush out the 56-MB buffer memory. The directory of the data written on the disk can be browsed by a "dir" command on the CRM in the SAM-191, although the data itself cannot be replayed through the serial link. On the "dir" command, the SAM-191 will reply with a list of system ID, stream ID, date of first data, date of last data, and total amount of data for a stream. The disk drives can be connected to a PC-compatible computer (PC) with a SCSI interface. A PC program called "scsiread" can replay the data written on the SCSI disk GCF format.

In parallel to saving the received data into the buffer memory, the SAM-191 also hands the data to another serial link for communication with an ROV via the four-pin female. The UMC provided by Ocean Design, Inc., is on top of the SAM canister. Because we assume an ROV may have a relatively slow link, such as 9600 bps, only slow data channels (≤20 sps) and status messages are passed to the ROV serial port. When the SAM-191 receives a pass-through request from the upstream ROV, it will organize the session. If the request is addressed to downstream modules, the SAM-191 passes the request to the MEG-191 to reach the addressed module.

Power consumption of the SAM-191 is ~1.0 W in the interval between disk transfers. When the SAM-191 disk is running, the power consumption increases up to an average of 26 W. The SAM-191 manages power in a similar way to the MEG-191. During disk operations, the SWB voltage is monitored against a preset threshold (23 V) and if it falls below this for ≥10 min, the disk transfer is aborted. This is done in an orderly way; the disk flushing task stops and the disk supply switches off. If this fails to finish in 5 min, the disk supply switches off. The SAM-191 also monitors the average voltage against a limit of 21 V and will automatically power down after 2 hr and remain shutdown for 24 hr, as in the MEG-191.

System Power Consumption

The power for the whole system is supplied by limited SWB power. Although a short-term increase or a sudden surge can be supplied by an accumulator in the battery system, the system will fail eventually if the long-term average power consumption is more than the capacity of the battery system. Thus, the power consumption of the system was carefully evaluated before the NEREID-191 system deployment in Hole 1179E.

T7. Power consumption of the NEREID-191 system, p. 58.

Table T7 summarizes the result of the power consumption measurement for the NEREID-191 system in Hole 1179E. When all the OBHs are running, we expect the power consumption of the whole system over a long period to be 9.1 W. The capacity of the SWB power supply is rated at 24 W, but it may vary depending on many environmental factors (see **"Seawater Battery,"** p. 15, in "Power Supply" for details). If the

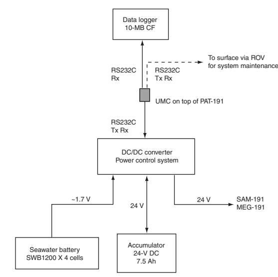
SWB capacity is <9.1 W, it will be necessary to shut off one of OBHs to save >3.3 W of power. The power management program in the CRM in the MEG-191 is designed to do this automatically.

POWER SUPPLY

Seawater Battery

The power for the NEREID-191 system is supplied by the SWB system. The battery system consists of four SWB-1200 (Kongsberg Simrad, Norway) cells (Hasvold et al., 1997), a DC/DC converter, the PCS, the DL, and an accumulator (Fig. F20).

F20. Schematic diagram of the seawater battery system, p. 41.



The cell is a magnesium/oxygen battery based on a magnesium anode, which uses seawater as the electrolyte and oxygen dissolved in the seawater as the oxidant.

The chemistry of the cell is the dissolution of magnesium at the anode,

$$2Mg = 2Mg^{2+} + 4e^{-},$$

and consumption of oxygen at the cathode,

$$O_2 + 2H_2O + 4e^{-} = 4OH^{-},$$

which is written in a simplified form

$$2Mg + O_2 + 2H_2O = 2Mg(OH)_2.$$

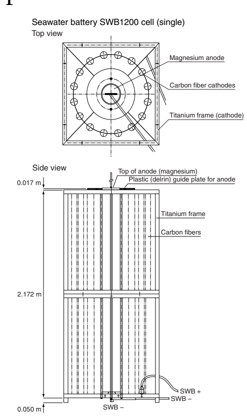
The formation of an alkaline product at the cathode surface may lead to the formation of a calcareous deposit,

$$4Ca^{2+} + 4HCO_3^{-} + 4OH^{-} = 4CaCO_3 + 4H_2O.$$

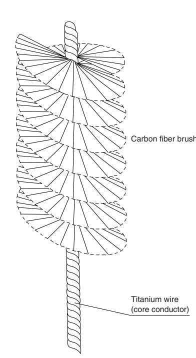
The alkaline reaction products need to be removed from the cathode surface by the sea current because the calcareous formation disturbs the second reaction at the cathode.

The anode is an AZ61 magnesium alloy rod with a diameter of 0.184 m and length of 2.2 m, including the anode connector device. The anode can be replaced by an ROV. The anode is surrounded by the cathode elements suspended from the titanium frame (Fig. F21). The weight in air of the anode is 120 kg and that of the titanium cathode frame is 40 kg. The cathode element consists of a titanium wire core with carbon fibers oriented radially (Fig. F22). The carbon fibers allow rapid material transport and high current density. The cathode collector lead (titanium wire) is connected to the titanium frame, which is also part of the cathode. The titanium frame is designed to allow seawater to pass easily through the cell so that oxygen-rich seawater is supplied to the cathode and the products of the cell reactions are removed.

F21. Seawater battery cell structure, p. 42.



F22. Structure of the carbon fiber brush used in the cell cathode, p. 43.



The cell voltage obtainable is ~1.6 V, although this largely depends on the conductivity of the seawater, which varies with the temperature and salinity. The catalytic effect of bacteria colonizing on the cathode surface, which has been observed on all seawater cells in previous deployments of the system, is also one of the many factors that affects cell voltage. The maximum cell power is limited by the rate of oxygen supply to the cathode. The oxygen supply rate is proportional to the oxygen concentration in the seawater and the speed of circulation. In order to produce the designed output of 6 W for each cell, a minimum circulation of 20 mm/s, an oxygen concentration of 3 ppm, and a salinity of 20‰ is required. Because the cells have an open structure, the isolation between cells is low, which leads to large leakage currents in serially connected cells. Thus, the cells are connected in parallel.

The 24-V DC/DC converter changes the low cell voltage (1.6 V) into the output voltage (24.0 V). The output of the 24-V DC/DC converter is fed to the accumulator, which averages the power demand on the 24-V DC/DC converter and the seawater cells. After deployment of the cells, the DC/DC converter is inactive until the cell voltage becomes >1.41 V. After the cells are activated, the 24-V DC/DC converter takes power from the cells and charges the accumulator as long as a sufficient cell voltage (>1.41 V) is available. If the cell voltage becomes <1.20 V, the 24-V DC/DC converter becomes inactive until the cell voltage is restored to 1.41 V.

The accumulator consists of multiple 2-V Cyclon (Hawker Energy) lead acid cells, which form a 7.5-Ah, 24-V cell in total. The accumulator cell is float-charged electrically by the 24-V DC/DC converter output (Fig. F20). The voltage of the accumulator output is 25.7 V when the accumulator cell is fully charged and has no charging voltage applied by the 24-V DC/DC converter. The cell is stored in a 6500-m depth-rated pressure housing, which has a four-pin GISMA series-10 underwater connector for the load output and the 24-V DC/DC converter.

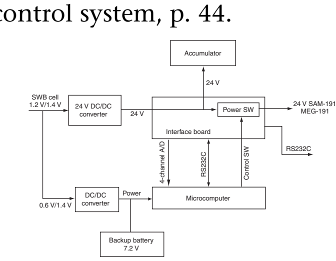
Power Control System

The PCS is a module that monitors and controls the SWB. The SWB system consists of the PCS, four SWB-1200 cells, the 24-V DC/DC converters, and the accumulator for supplying power to an external 24-V DC-driven system (e.g., SAM-191 and MEG-191) (Fig. F20). The 24-V DC/DC converter and the PCS are in the same canister. The purposes of the PCS are to monitor the voltages and currents of the SWB-1200 cells, the accumulator, and the output of the SWB system and to control the power switch of the SWB system to protect the accumulator from overdischarge.

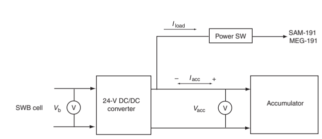
SWB conditions are sampled by a microprocessor, and the sampled data are time-stamped and sent to the external data storage (DL) by an RS232C serial connection. Because the UMC is used for the connection between the PCS and the DL, an ROV can be connected via the same connector to the PCS and then via a serial line, it can check and control the PCS at the time when the DL is disconnected.

The PCS consists of a microcomputer, an interface board, a small DC/DC converter, and a backup battery (Fig. F23). The PCS will monitor the input voltage to the 24-V DC/DC converter and all the output voltage and current distributed from the accumulator. The microcomputer has a four-channel A/D converter to read voltages and currents. The A/D converter in the microcomputer samples the voltage of the SWB cells (V_b), the voltage of the accumulator (V_{acc}), the current for the load (I_{load}), and the current of the accumulator input (I_{acc}) (Fig. F24). The current value of the accumulator includes the direction of current flow (e.g., if the accumulator is charging or discharging). The sampling interval can be changed by sending commands to the microcomputer across the RS232C line. The RS232C line is used for communication between the microcomputer and the interface board.

F23. Block diagram of the power control system, p. 44.

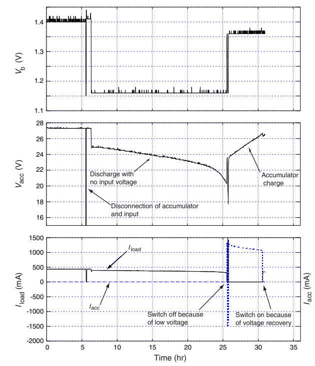


F24. Voltages and currents measured by the power control system, p. 45.



The power switch on the interface board is controlled by the microprocessor. The microprocessor turns the power switch off to protect the accumulator under certain conditions. When the voltage of the accumulator is <18 V, the PCS immediately turns off the power switch. The PCS also turns off the power switch when the PCS detects three continuous accumulator readings of <20.8 V under small current conditions (<0.5 A). Three continuous readings take ~20 min. When the power switch is turned off and the voltage of the accumulator is >26.5 V, the PCS turns the power switch on. This procedure will be performed after three continuous readings of the PCS (Fig. F25). A small DC/DC converter supplies the power to the PCS from SWB cells. The DC/DC converter is the same as the 24-V DC/DC converter for the accumulator; however, the active voltage of the DC/DC converter is lower than that of the 24-V DC/DC converter. When the voltage from the SWB cells increases, the DC/DC converter becomes active at a voltage of 1.4 V. When the voltage of the SWB cells becomes <0.6 V, the DC/DC converter stops the conversion of voltage. When the DC/DC converter for the PCS does not supply power, the PCS takes power from the backup battery. The lifetime of the backup battery is ~250 days with a sampling interval of 60 s. The PCS consumes 85 mW of power while reading the voltages and the currents and 29 mW in sleep mode. When a lithium backup battery is connected within the canister, the microprocessor starts sampling at an interval that has been set to 60 s. The PCS transmits the data to an RS232C output and no acknowledgement is used in the protocol. After the transmission of the data, the PCS checks the voltage and current limits and takes actions based on these results by turning the external load switch on or off.

F25. Variation of voltages and currents in the seawater battery system, p. 46.



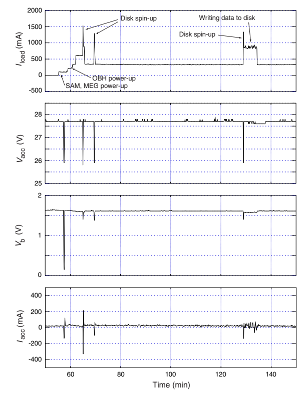
The PCS can be configured through an RS232C line using a PC. Usually, we use the program *Serikom,* which is provided by Kongsberg Simrad. The PCS can be programmed to different interval sampling times by setting the wanted time into the SLEEP_TIME windows on the program. The program has a command (MEASURE_NOW) to read voltages and current immediately. Using this command, a measurement is sent from the PCS, overriding the SLEEP_TIME setting. The power switch can be controlled by sending a command (SWITCH_ON/SWITCH_OFF) to the PCS. After receiving the command, the PCS immediately turns the power switch on or off. The sampling interval and the status of the power switch can be checked using the command READ_REGISTER. RTC time in the PCS can be set from a PC using the DOWNLOAD REALTIME CLOCK command. This setting resets the PCS system. The Serikom program also displays ordinary measurements from the PCS.

Data Logger

Data stored in the DL can be retrieved by an ROV. A simple PC program is used to examine the data and empty the DL. The DL consists of a single card computer, provided by Persistor, with a serial interface and a 10-MB flash storage device. A voltage of 7.2 V is supplied to the DL using 24 D-size lithium cells. The cells have a voltage of 3.6 V and a capacity of 16 Ah. After connecting the power line, the DL switches between two modes. In the suspended mode, the DL switches off all devices on the DL, except the serial controller interface, to minimize power consumption. The DL is turned on when the PCS starts sending data over a serial communication line. The data consist of current and voltage readings from the DC/DC converter. The baud rate for the serial communication is set to a fixed rate of 4800 baud. The DL will read the data from the PCS and save them to the flash memory drive in a format as the *$M, string*. When the DL finishes reading the data from the PCS, it goes back into a suspended mode. When the flash drive has reached its data-storage capacity, logging of data from the PCS is stopped. The recording period of the DL deployed during Leg 191 is ~160 days at a sampling interval of 60 s. The power consumption of the DL is 28 mA in normal operation and 0.3 mA in suspended mode.

When the DL has been retrieved by an ROV, the data stored on the flash card in the DL can be taken out for data retrieval. The data are saved on the flash card in ASCII format to a file called *pcsdata.log,* and it can be read into a PC. According to limitations of the operating system of the microcomputer (called PicoDOS), the file on the flash cards is never erased or changed using the PC. We show examples of records in the DL from testing of the equipment before Leg 191 in Figure **F26.**

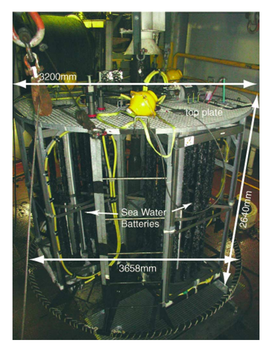
F26. Records from the power control system during the final equipment test, p. 47.



Battery Frame

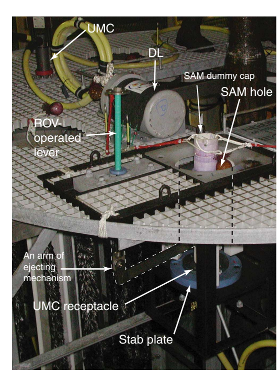
The SWB system is mounted on the cylindrical PAT frame, as shown in Figure **F27.** Four SWB cells are stored in concentric positions. The PAT frame is made of ordinary steel angle but is coated with zinc, and its base part is also coated with tar epoxy paint to protect it from corrosion. The titanium frame of the SWB cell, the stainless steel pressure housings for the DC/DC converter, and the accumulator are mounted on the PAT with polyvinyl chloride insulators. The top of the PAT is a gray, flat panel made of fiber-reinforced plastic drainboard that has access holes for the SWB anodes. The flat panel serves as the ROV platform. The panel is reinforced by a metal frame and is circular when viewed from above. The diameter of the top panel is 3.2 m. The basal "leg" of the PAT is also circular, and the diameter is 3.66 m, which corresponds to the diameter of the reentry cone. The basal leg is 0.24 m in height. The leg lifts the battery cells to improve the seawater circulation through the cells and to keep the PAT stable on the reentry cone. In the center of the PAT frame, coaxial rings are placed to guide the PAT smoothly over the riser assembly during installation. The hole in the center of the top panel provides space for the MEG frame. The total height of the PAT is 2.64 m to accommodate the SWB cells. The vertical position of MEG-191 on the riser is set to allow ROV operations.

F27. Photograph of the power access terminal in the moonpool area, p. 48.



The PAT also holds the SAM-191 recorder beneath its top panel. The top part of the SAM-191 sticks out of the panel. The UMC at the bottom of the SAM bulkhead is mated by gravity into a UMC receptacle, mounted on the stab plate placed at the bottom of the SAM hole, when the SAM-191 is dropped in the hole. In the dropping operation, the hole keeps the SAM-191 canister in the upright position. The SAM-191 key is lowered to the guiding wedges prepared inside the hole. At this time, the connectors on the bottom bulkhead of the SAM-191 canister are correctly positioned to the mating orientation of the UMC. The cable from the UMC at the bottom of the SAM hole receptacle has a T-junction; one branch is connected to the SWB system, and the other goes to a UMC receptacle mounted on the PAT top panel. Another cable (the ROV cable) is installed on the panel and is used to connect the UMC receptacle on the top panel to the MEG-191 canister. The ROV cable is fastened to the top panel initially by fastening mechanisms and a parking connector for the ROV UMC plug. An ROV will take off the fasteners and connect the ROV UMC plug to the MEG-191 canister. The SAM-191 can be ejected by an ROV-operated lever mechanism in the recorder frame (Fig. **F28**). The lever can be locked at two positions, one at

F28. Photograph of the recorder frame of the storage acquisition module with a dummy cap, p. 49.



the mated position of the SAM-191 and the other at the released position. By the use of the locking positions, an ROV can easily replace the SAM-191 recorder.

The DL was set on the top panel of the PAT (Fig. F28) and was retrieved by an ROV in October 2000.

SHIPBOARD AND ROV OPERATIONS

Operation of WP-2 Observatory

As soon as the NEREID-191 system was installed in Hole 1179E, the SWB started charging the accumulator (see "Power Supply," p. 15). The downhole OBH sensors (see "Borehole Instruments," p. 6), however, did not start functioning until an ROV arrived at the site to activate the NEREID-191 system.

On 29 October 2000, *Kaiko* (Fig. F29), an ROV designed by the Japan Marine Science and Technology Center (JAMSTEC) to operate in water depths of up to 10,000 m, visited Site 1179 to activate the WP-2 observatory. Before the ROV dive, another SAM housed in a titanium sphere was deployed by free fall from the mother ship, *Kairei*. The ROV completed the following operations:

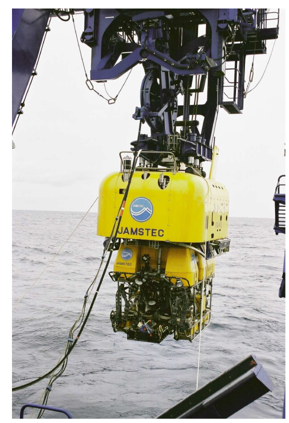
1. Removed the dummy SAM from its seating frame located on the top of the PAT.
2. Temporarily inserted the SAM-191 onto the seating frame.
3. Made a connection between the MEG-191 and the PAT.
4. Checked on the status of the NEREID-191 system using the SAM/ROV interface.
5. Looked for the titanium-sphere SAM on the seafloor and carried it to the PAT.
6. Placed the titanium-sphere SAM on the top of the PAT.
7. Disconnected the PAT from the MEG-191 and the SAM-191.
8. Made a connection between the MEG-191 and the titanium-sphere SAM.
9. Removed the SAM-191 from the seating frame.
10. Removed the DL from the PAT.
11. Brought the DL and the SAM-191 back to the sea surface.

(See "Seafloor Instruments," p. 9, for MEG and SAM information; see "Power Supply," p. 15, for PAT and DL information.)

In the original plan, the SAM-191 unit was to be installed on the PAT at the time of the installation of the WP-2 observatory at Hole 1179E. During Leg 191, it was decided, however, not to lower the SAM-191 down to the seafloor with the PAT because there was a significant probability of poor sea conditions around Site 1179 in October 2000, when the ROV was scheduled to visit the site. Poor sea conditions might have prevented the ROV from diving to activate the NEREID-191 system during its planned visit to Site 1179. If the NEREID-191 system had been activated during Leg 191, the SAM-191 would have started to work and consumed its internal battery while the OBH sensors and the MEG-191 were inactive. To avoid the wasteful consumption of the battery, we decided to install the SAM-191 at the time of the ROV visit in October 2000.

After the SAM-191 is installed on the PAT, the NEREID-191 system activates as soon as the electrical connection between the MEG-191 and

F29. ROV *Kaiko,* which activated the NEREID-191 in October 2000, p. 50.



the PAT is made using the UMCs. Power is supplied to the OBH sensors, the MEG-191, and the SAM-191 from the accumulator. Once this connection is made, data from the OBH sensors start to flow into the SAM-191 on the PAT, which can store 72 GB of data, sufficient to record 590 days of observations.

The ROV can check the status of the system via a SAM/ROV interface that allows RS232C communication between the SAM-191 and the ROV. If there are no problems, the ROV needs only to swap the SAM-191 at least once every 1.5 yr for no loss of data continuity.

The SWB battery life is somewhat unpredictable because it is strongly dependent on such factors as bottom-water currents and dissolved oxygen. The NEREID-191 system at Site 1179, which is different from the previous ones installed at Sites 1150 and 1151 (Sacks, Suyehiro, Acton, et al., 2000), has PCS and DL (see **"Power Supply,"** p. 15) units that can monitor and record the voltage and the current provided from the SWB to the system. The pressure vessel of the DL unit was set on top of the PAT. We were able to retrieve the DL unit with an ROV. Power-supply data recorded in the DL give us important information of the exact battery life of the SWB at Site 1179.

Because the performance of power generation of the SWB could not be assessed until recovery of the DL, we prepared another SAM that has lithium battery cells during the first dive of the *Kaiko* and decided to connect the SAM with lithium batteries to the MEG-191 for the first observation period in 2000. The SAM is housed in a titanium sphere with five lithium battery cells. The lithium batteries have a total capacity of 1300 Ah and supply the power to the whole system of the WP-2 observatory. A UMC is mounted on top of the titanium sphere to make a connection directly to the MEG-191.

The seafloor downhole observatory is still at the pilot study stage. There is no routine setup that one can rely on. In our design, the OBH sensor string is unrecoverable for the reasons given in **"Installation Techniques,"** p. 4. This necessitates that the string be composed of highly reliable instruments (see **"Borehole Instruments,"** p. 6). On the other hand, the seafloor components are virtually all replaceable and serviceable by an ROV. The SAM-191 or the titanium-sphere SAM is replaced at each ROV visit. The MEG-191 can be pulled out of its seating frame and reinserted by an ROV, although the operation is more complex than other tasks.

REFERENCES

Hasvold, Ø., Henriksen, H., Melvær E., Citi, G., Johensen, B.Ø., Kjønigsen, T., and Galetti, R., 1997. Sea-water battery for subsea control systems. *J. Power Sources,* 65:253–261.

Ocean Drilling Program, 1996. *Understanding Our Dynamic Earth through Ocean Drilling: Ocean Drilling Program Long Range Plan Into the 21st Century:* Washington (Joint Oceanographic Institutions).

Sacks, I.S., Suyehiro, K., Acton, G.D., et al., 2000. *Proc. ODP, Init. Repts.,* 186 [CD-ROM]. Available from: Ocean Drilling Program, Texas A&M University, College Station, TX 77845-9547, USA.

Stephen, R.A., Collins, J.A., and Peal, K.R., 1999. Seafloor seismic stations perform well. *Eos,* 80:592.

Figure F1. Location map of seismic station coverage in the northwest Pacific. Solid circles mark the location of land seismic stations, whereas open circles mark current and proposed seafloor borehole observatories. The shaded circle marks the location of Hachijojima (HCH), a planned seismic station. YSS =Yuzhno Sakhalinsk, Russia; NMR = Nemuro, Japan; PHN = Pohang, Korea; OGS = Chichijima, Japan; MCSJ = Minami-torishima, Japan; ISG = Ishigakijima, Japan; TGY = Tagaytay, Philippines; PATS = Ponphei, Micronesia; PMG = Port Moresby, Papua New Guinea.

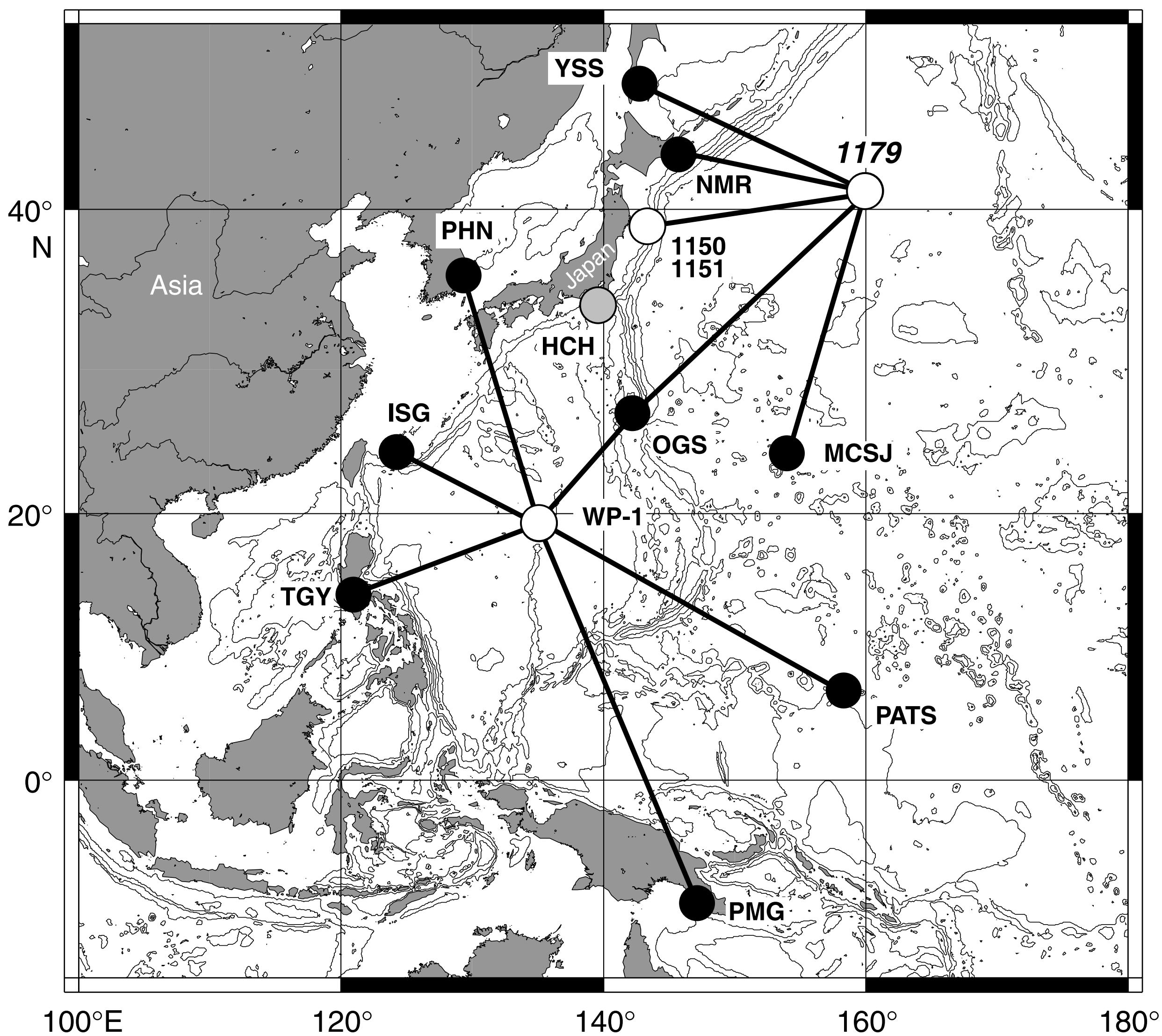


Figure F2. Schematic view of the NEREID-191 system of the WP-2 borehole seismological observatory. ROV = remotely operated vehicle, DL = data logger, PCS = power control system, BIA = borehole instrument assembly.

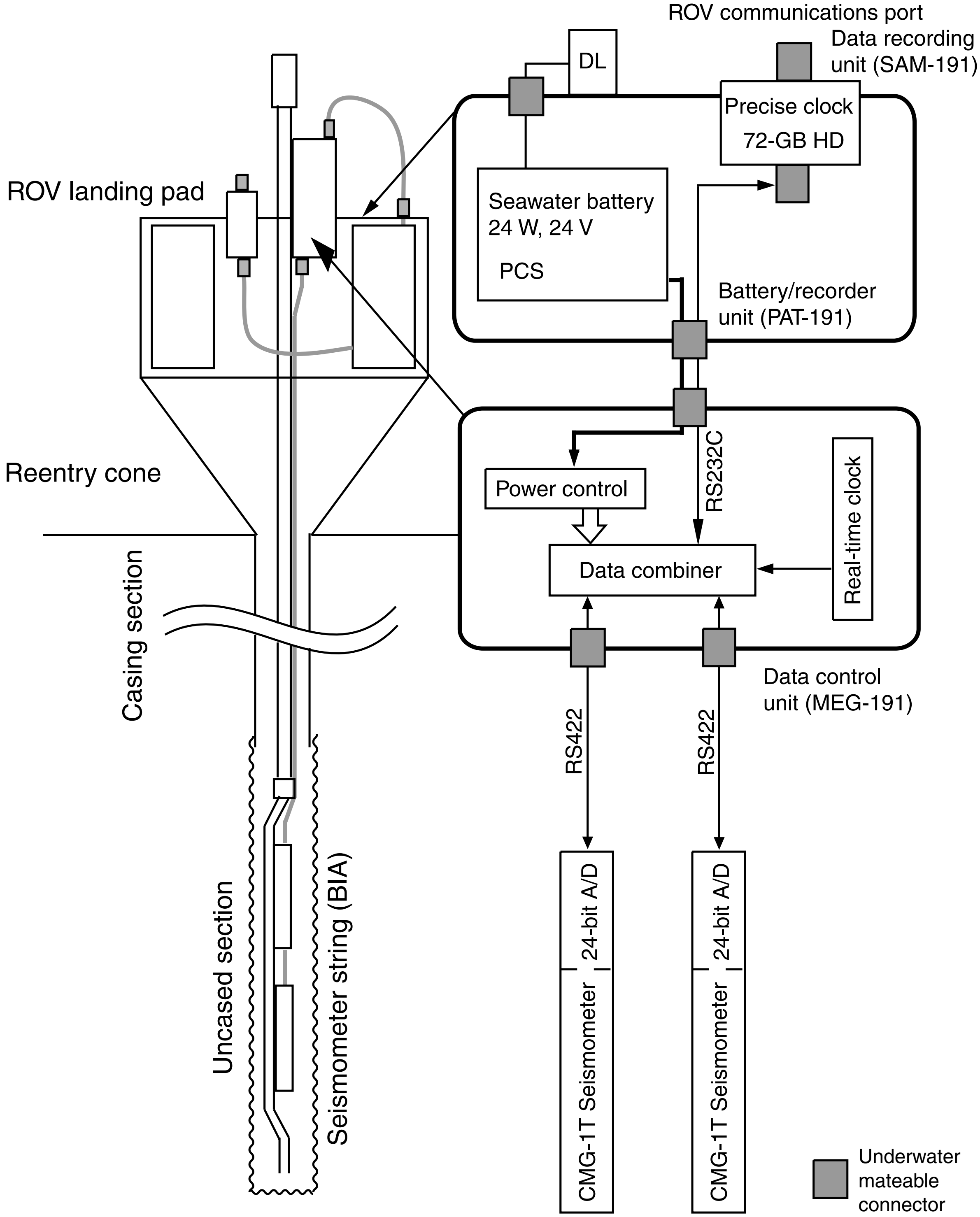


Figure F3. Borehole instrument assembly (BIA) installation schematic. The BIA hangs on a 4.5-in casing pipe, which in turn hangs on the riser hanger support just below the reentry cone. The cables from the sensors are strapped to the casing pipe with tie wraps and duct tape and protected by centralizers. Cement is pumped through the 4.5-in casing pipe and the BIA and out the bottom of the stinger. Cement is pumped to completely fill the bare hole and to extend into a lower part of the 10.75-in casing. The sensors are thus strongly coupled to the bare rock. PAT = power access terminal, MEG = multiple-access expandable gateway.

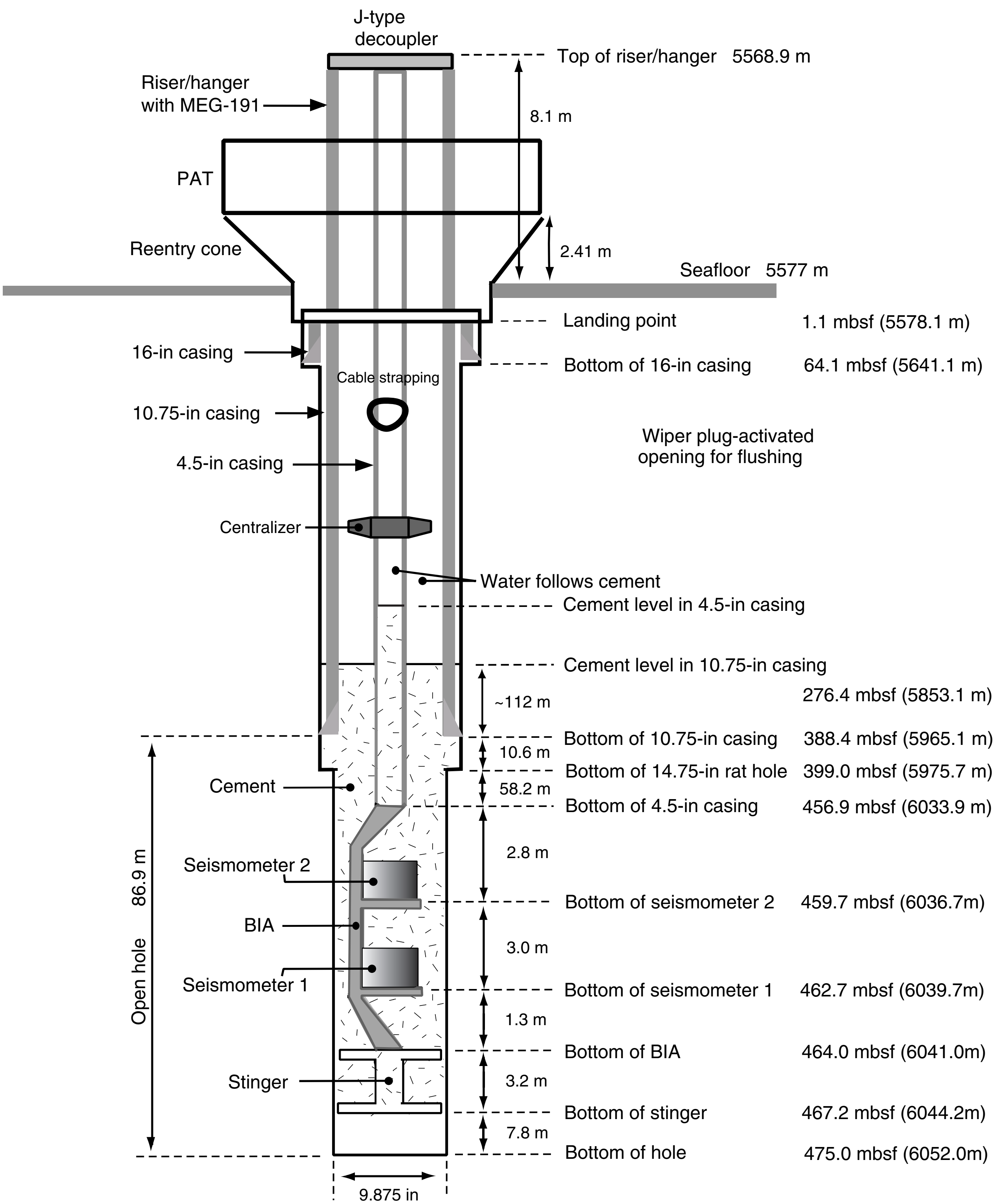


Figure F4. Cable strappings and centralizer.

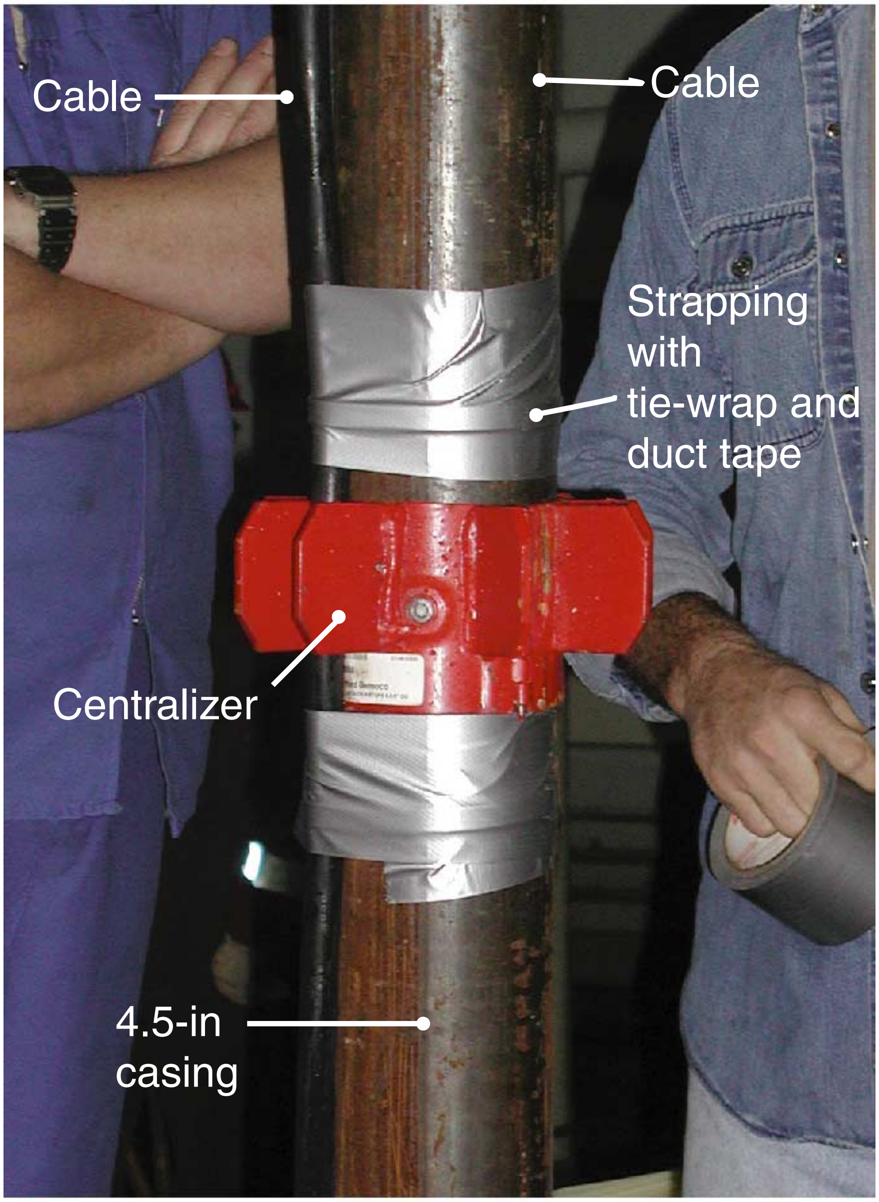


Figure F5. Instrument placement. Note that the seismometers are not electrically in contact with the borehole instrument assembly (BIA).

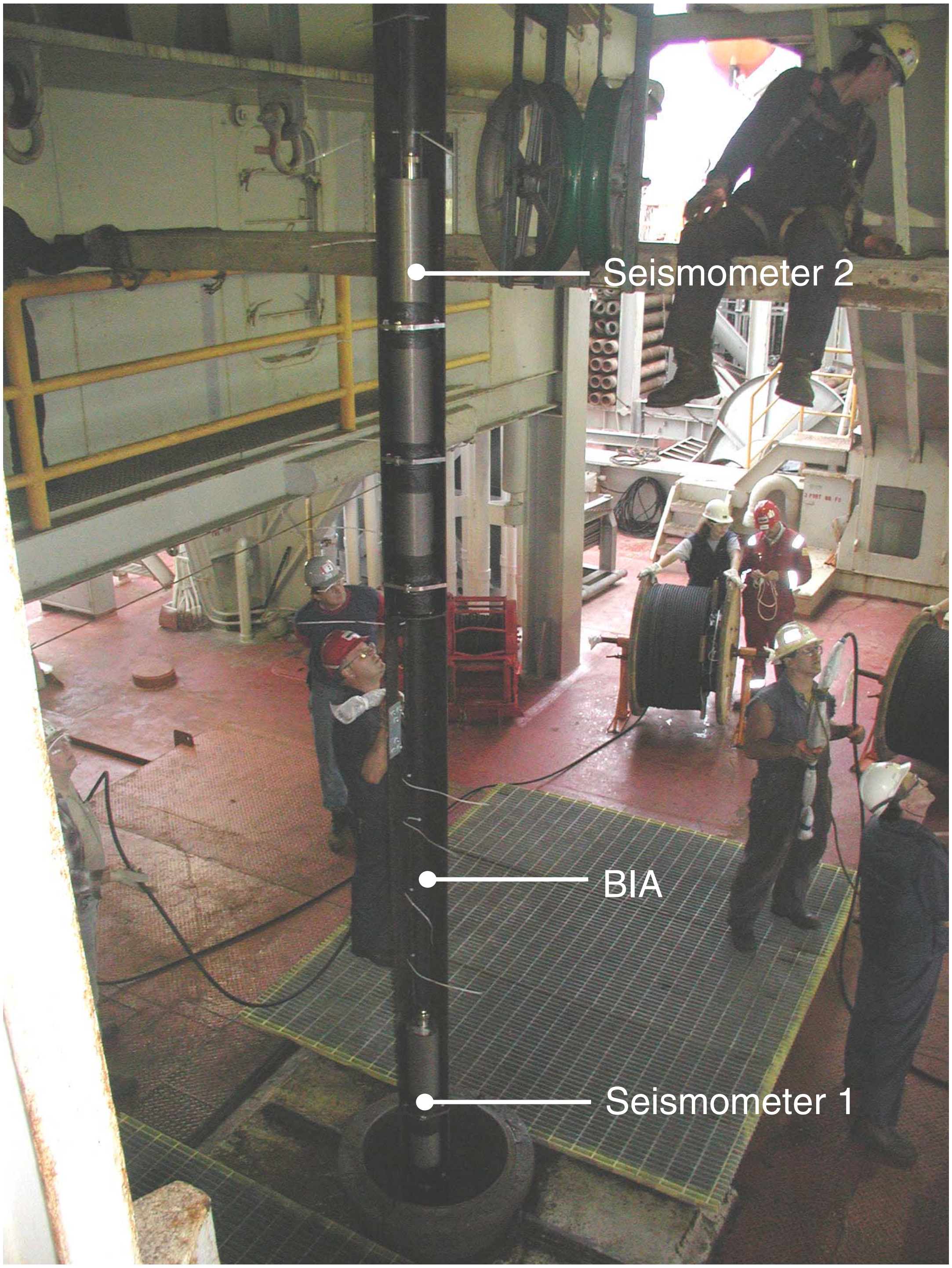


Figure F6. Appearance of the borehole instrument assembly (BIA). The BIA consists of a frame pipe and two blades. Its shape looks like a bottom of a ship. Two ocean borehole seismometer (OBH) sensors are emplaced on the BIA.

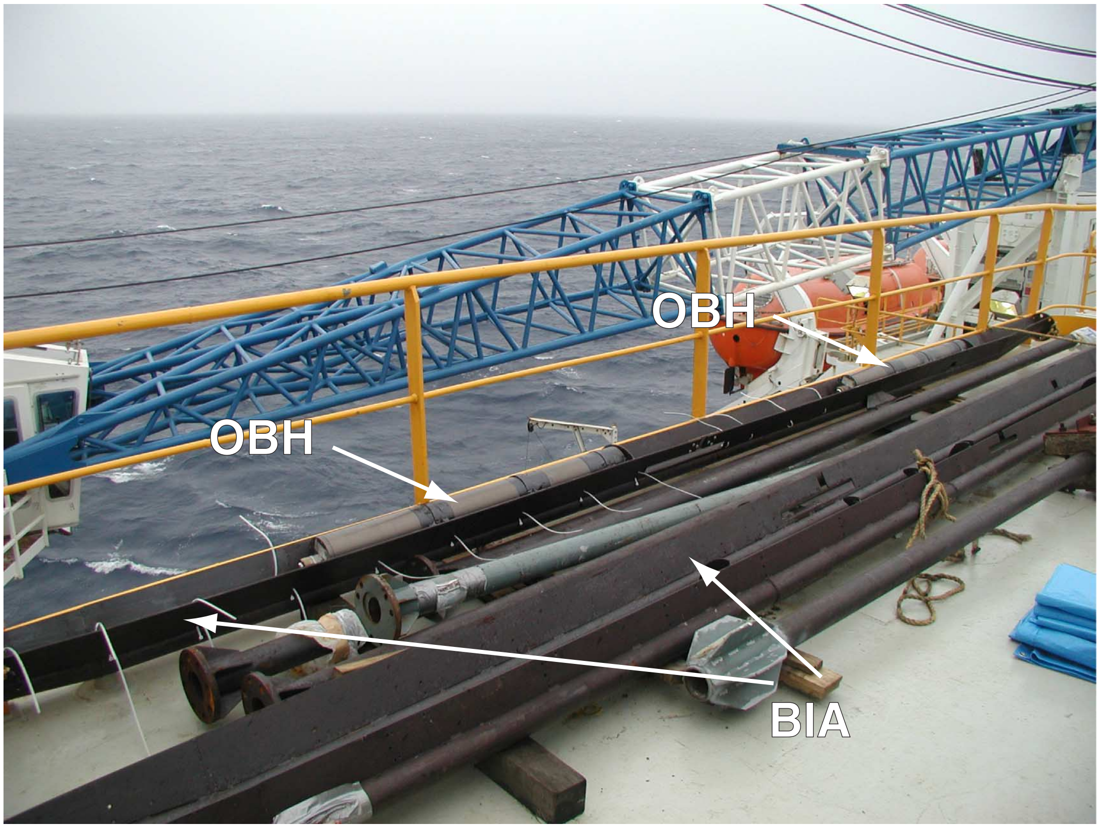


Figure F7. An ocean borehole seismometer (OBH) sensor was emplaced on the borehole instrument assembly (BIA) within the area enclosed by two blades.

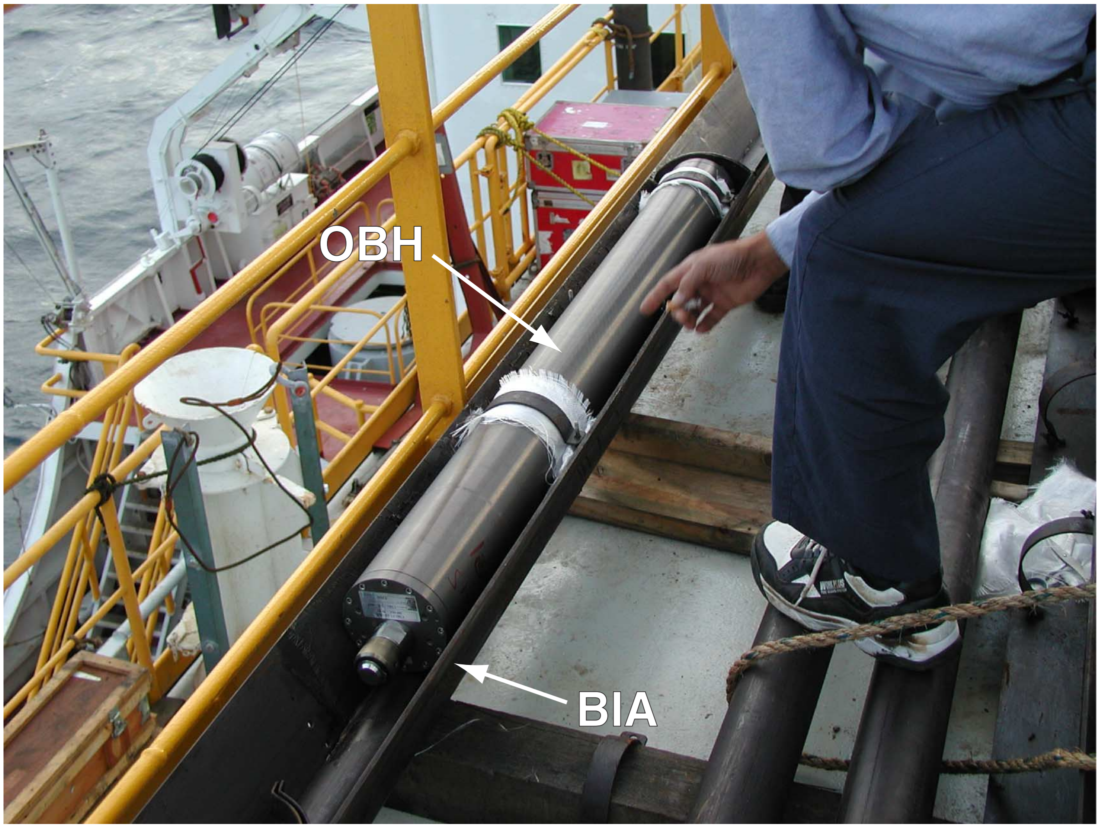


Figure F8. Installation of the borehole instrumentation assembly (BIA) in the moonpool area. After affixing the ocean borehole seismometer (OBH) sensors onto the BIA, the BIA was moved to the moonpool area for installation into the borehole. Cable connections to the OBH sensors were made.

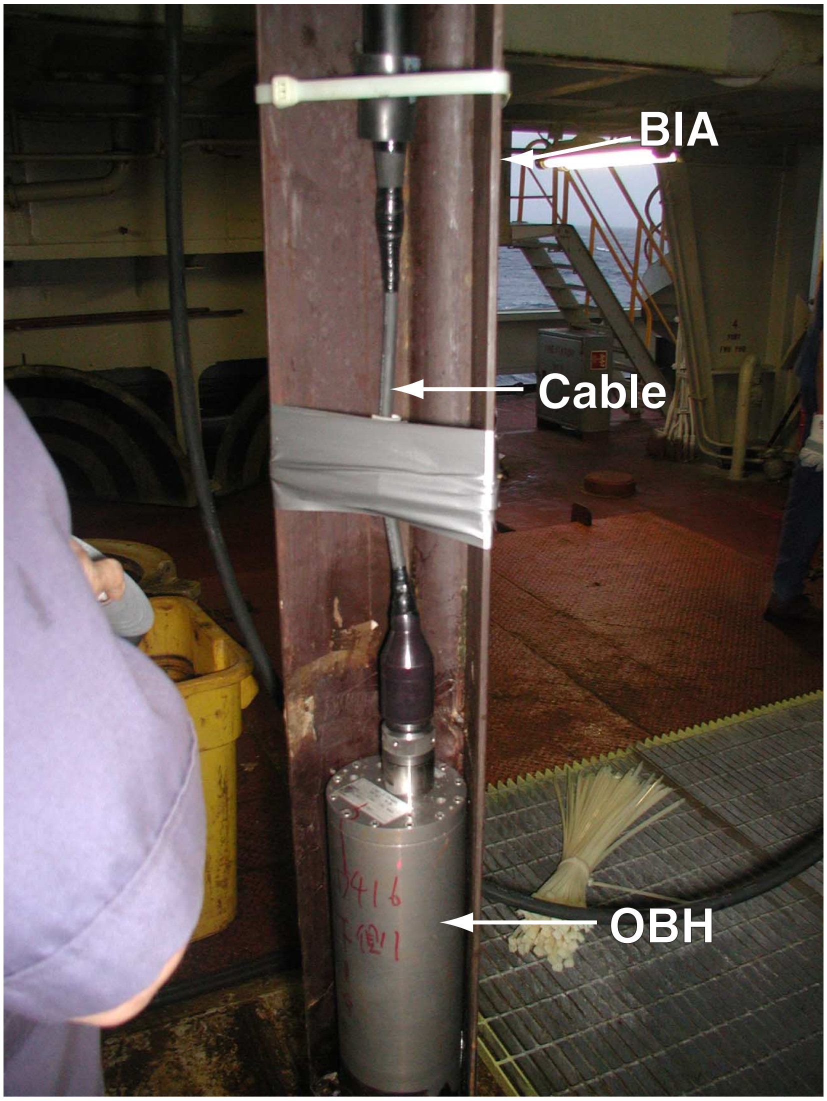


Figure F9. Installation of the borehole instrument assembly (BIA) in the moonpool area. After connecting the cables to the ocean borehole seismometer (OBH) sensors, cables were tied to the BIA with plastic tie wraps and duct tape.

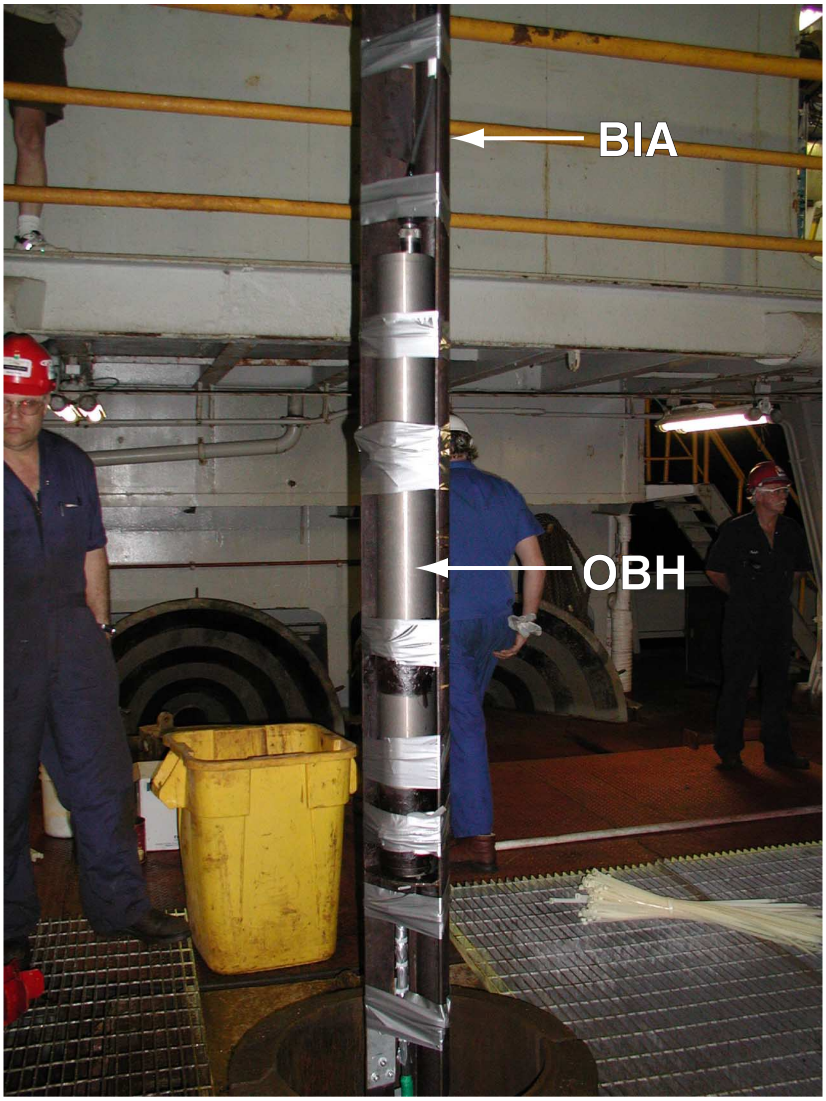


Figure F10. Insulation between the ocean borehole seismometer (OBH) sensors and the borehole instrument assembly (BIA) was made using fiberglass cloth.

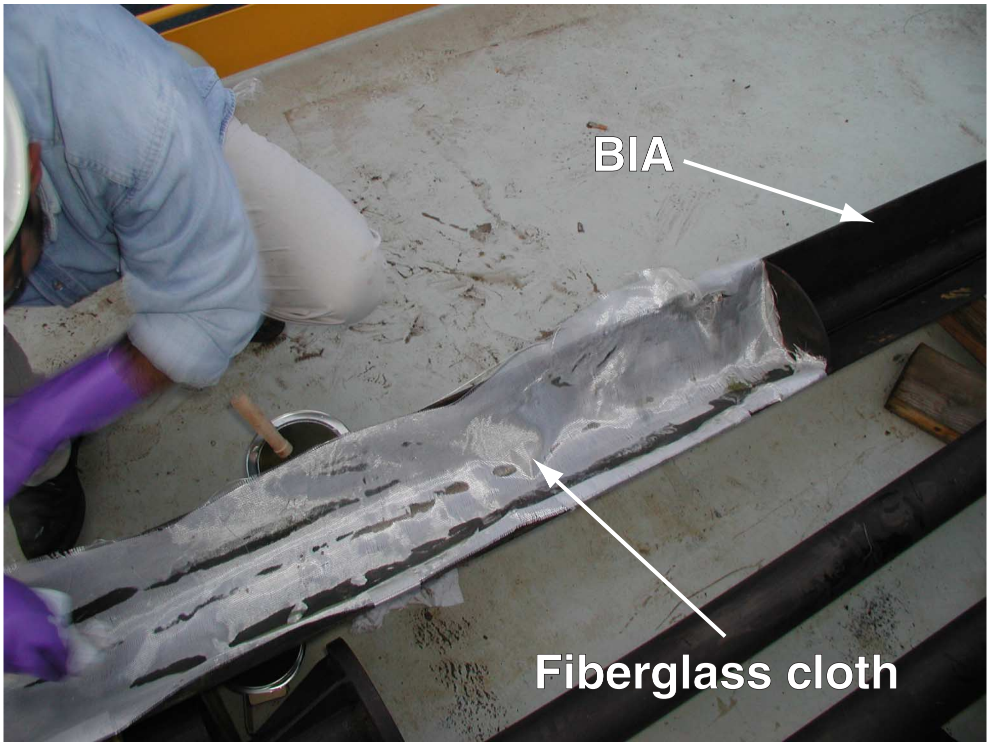


Figure F11. Fiberglass cloth was glued over surfaces of the borehole instrument assembly (BIA) where the ocean borehole seismometer sensors were affixed.

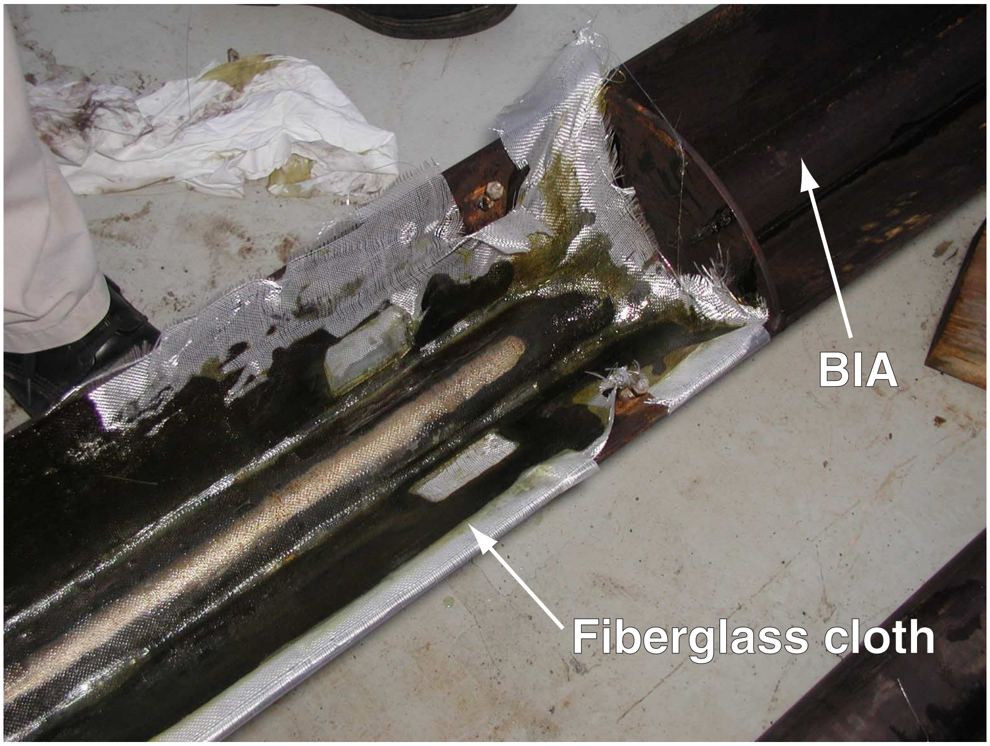


Figure F12. Drawing showing the components of the ocean borehole seismometer used for Leg 191 installation. The undersea connector on the top bulkhead is an eight-way SEACON titanium base connector. The digitizer electronics and sensor stack are connected by a cable to the miniature 26-way D-type connector on top of the sensor stack. Modified from Sacks, Suyehiro, Acton, et al., 2000.

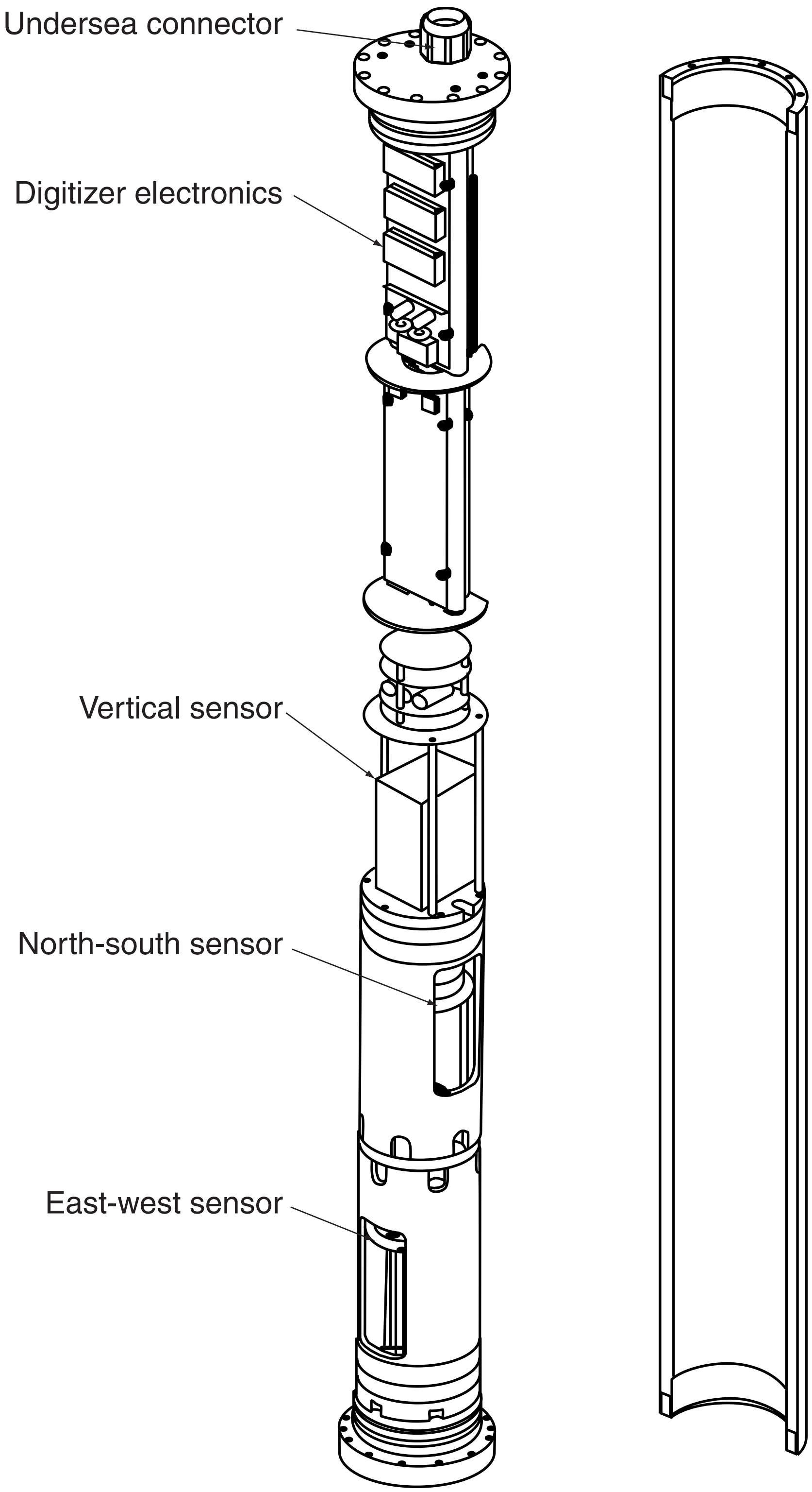


Figure F13. Cutaway drawing of the CMG-1T vertical sensor. The unit that appears in the drawing is mounted on a brass base, which holds the electronics circuit boards as well.

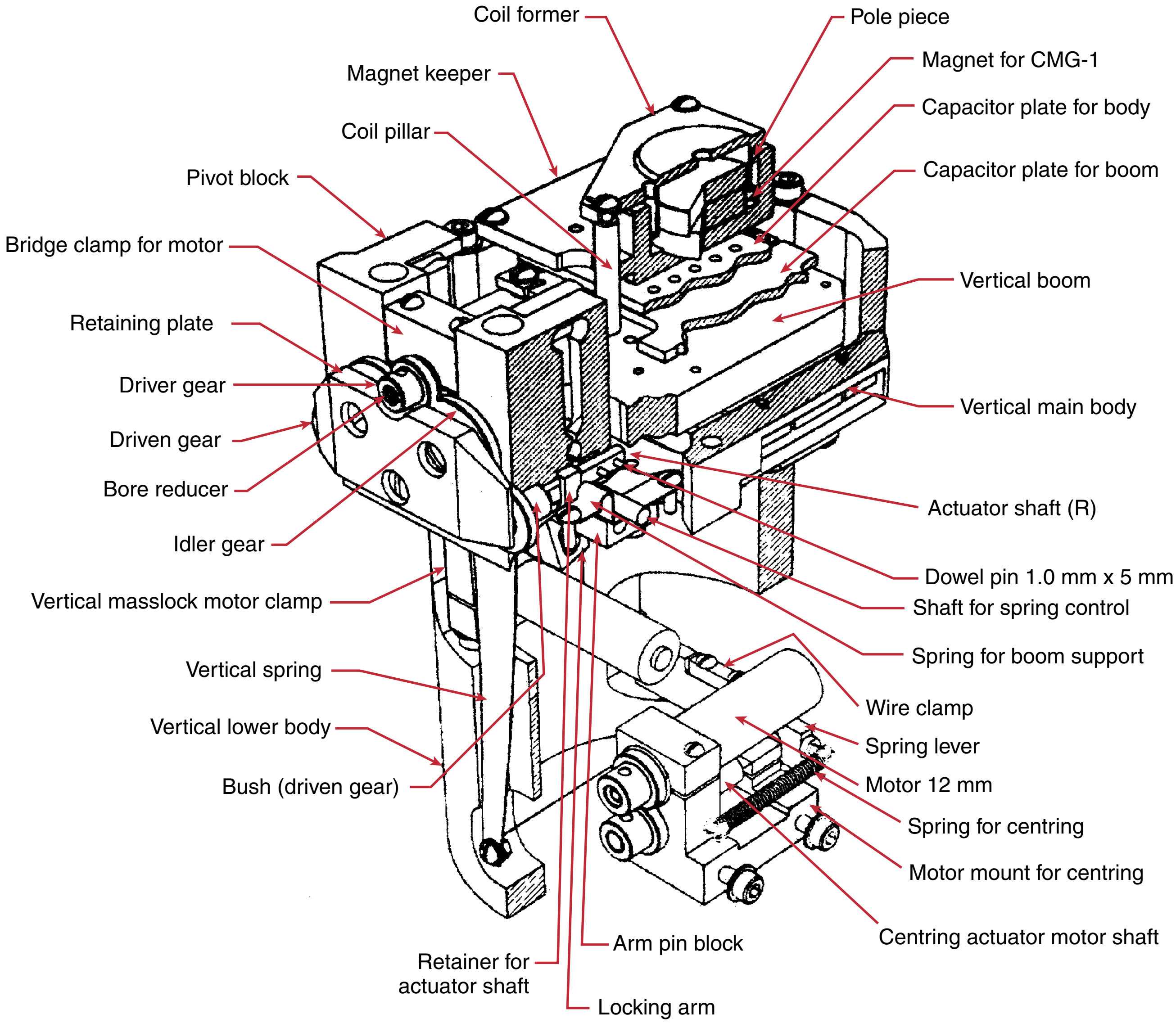


Figure F14. Schematic diagram for the electronic circuits of the CMG-1T sensors. The seismometer power and the state of health (SOH) circuitry are common for all three sensors, whereas the other parts consist of separate units for each sensor. Modified from Sacks, Suyehiro, Acton, et al., 2000.

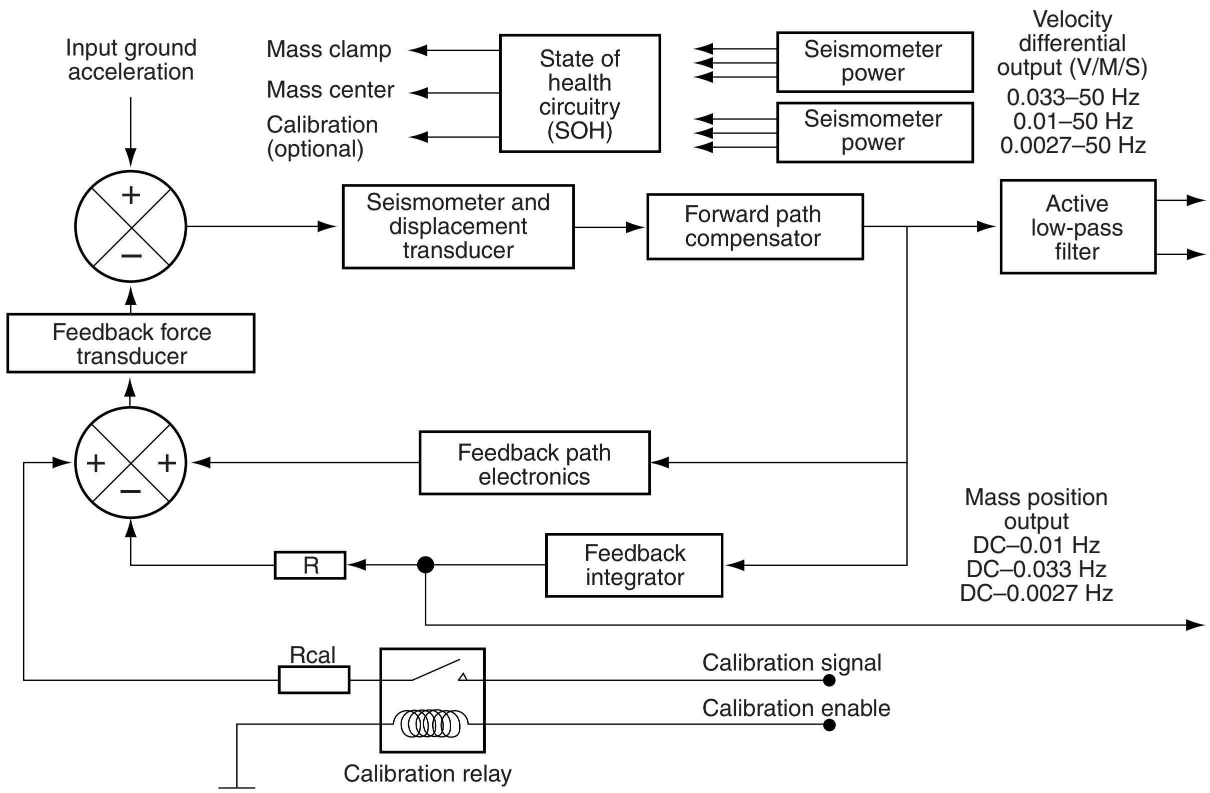


Figure F15. Spectra of the instrument self noise for the horizontal components of the ocean borehole seismometers (OBHs) deployed during Leg 191. Because the spectra were estimated from records of ~3 min, the results at <0.05-Hz frequency have low reliability. The noise curves are compared with the observed short-period noise level for the OBH deployed in Hole 1150D during Leg 186 (dashed line). The OBH self-noise curves were estimated by taking the incoherent power spectrum for ground-noise records of two adjacent OBHs deployed at Nokogiriyama vault in Chiba, Japan, on 14 July 2000. The increase of the ~2-s period noise level is due to insufficient reduction of the large ground noise. The legend (lower right) shows curves representing the comparison of different pairs of sensors (sensors 5, 6, and 7).

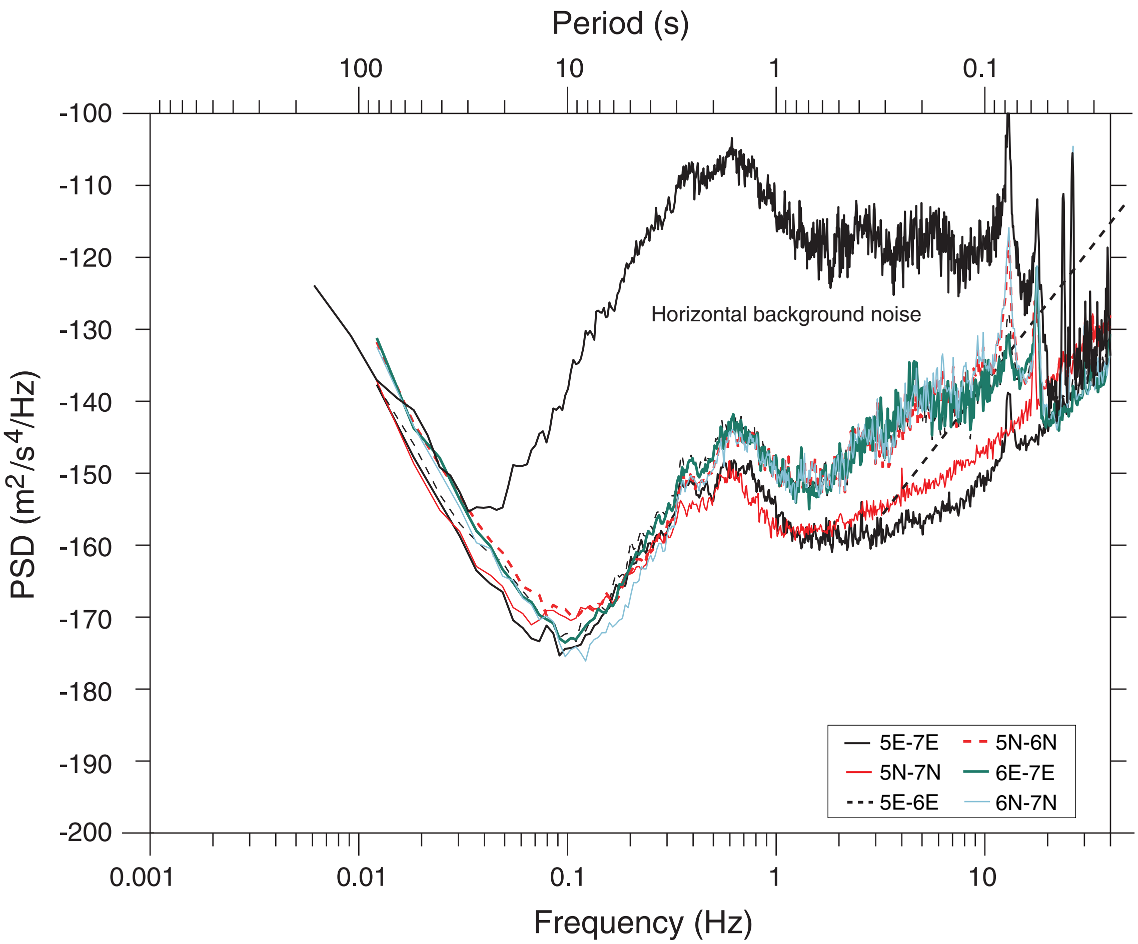


Figure F16. Schematic diagram of the DM24 digitizer. FPGA = field programmable gate array, DSP = digital signal processor, RAM = random access memory, GPS = Global Positioning System, UARTS = universal asynchronous receiver transmitters. Modified from Sacks, Suyehiro, Acton, et al., 2000.

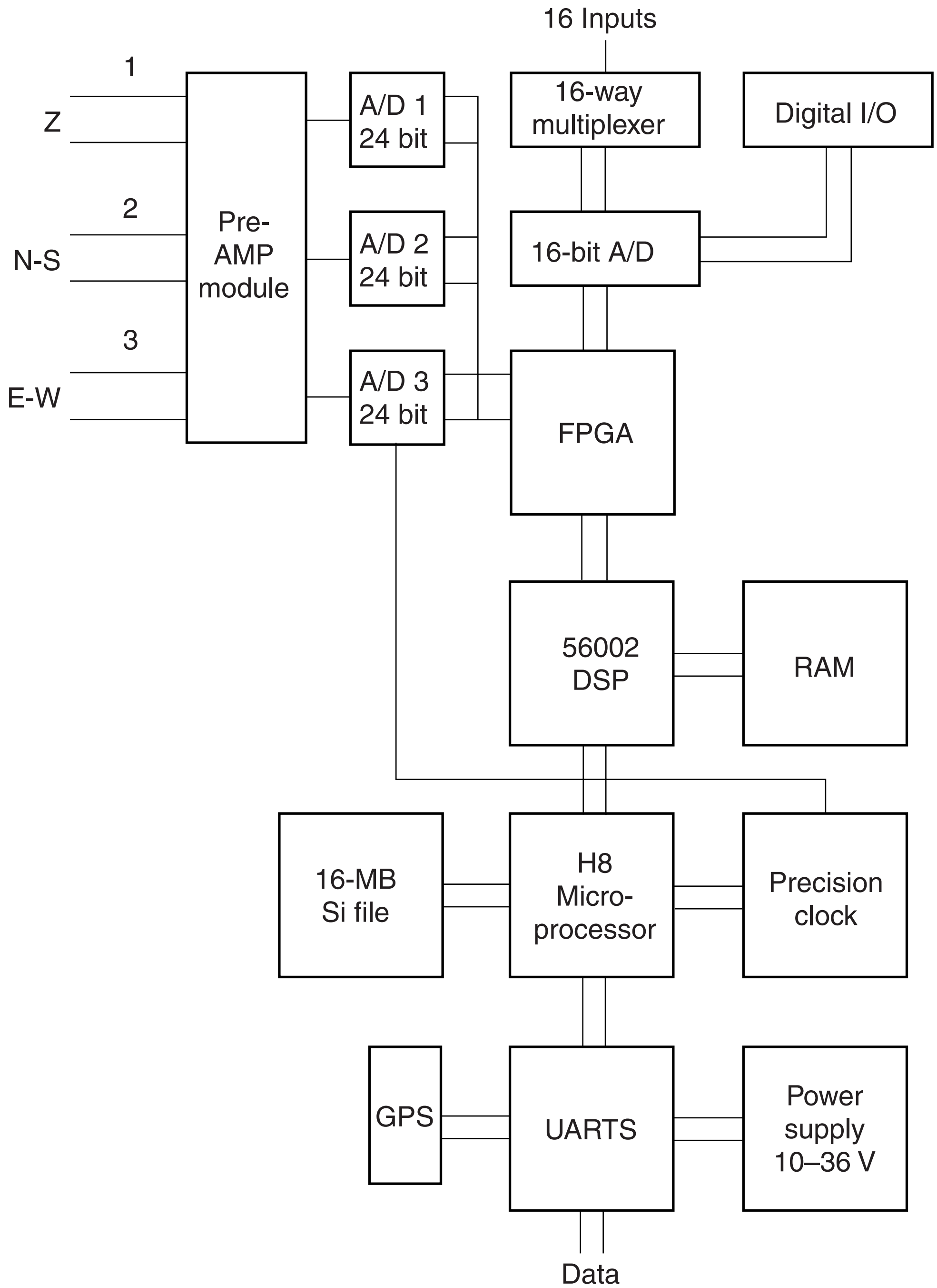


Figure F17. MEG-191 system block diagram. SWB = seawater battery, PDM = power distribution module, OBH = ocean borehole seismometer. SAM = storage acquisition module, MOS = metal oxide semiconductor, FET = field-effect transistor, CRM = combiner/repeater module, TTL = transistor transistor logic.

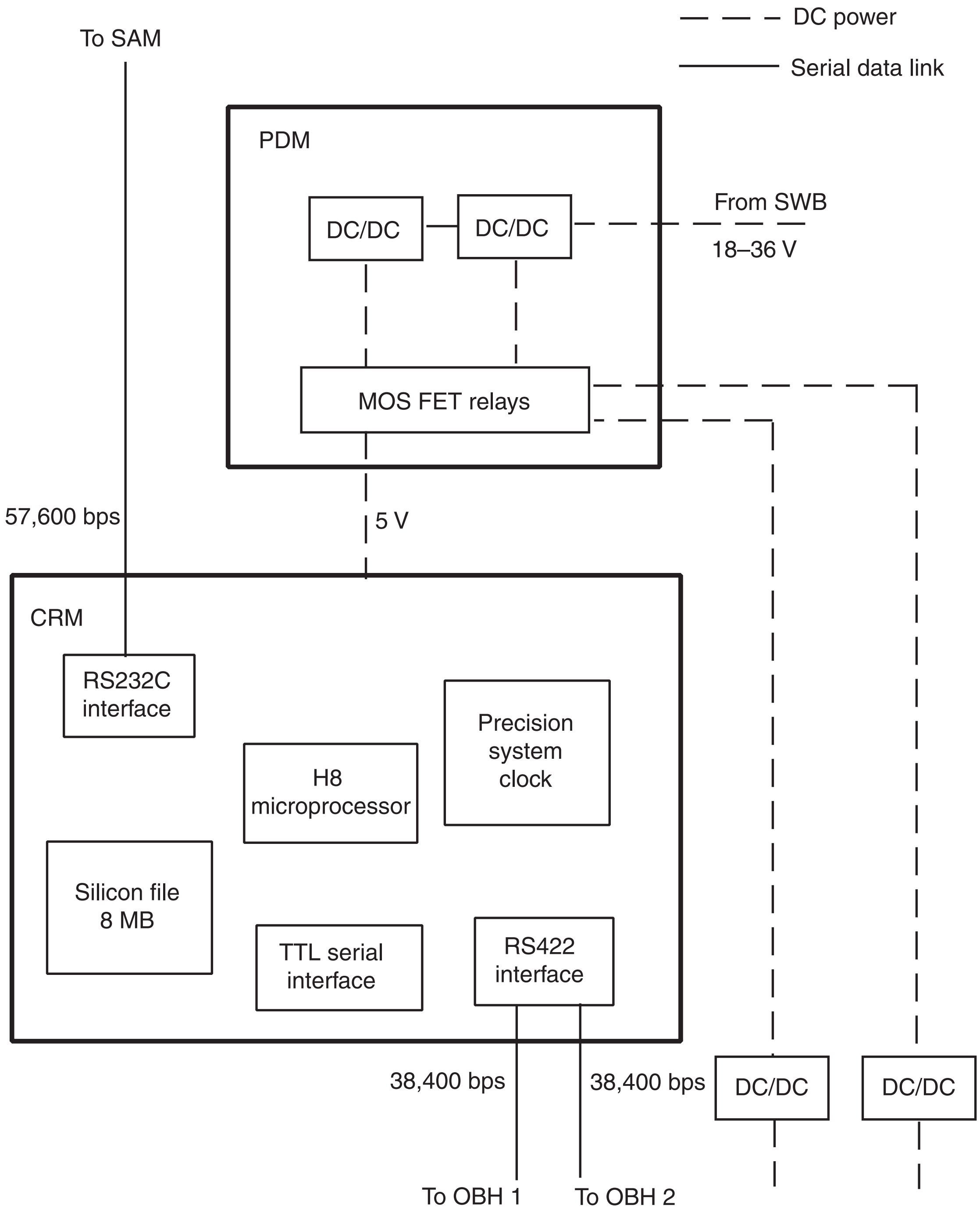


Figure F18. Photograph showing the MEG-191 vessel installed in the multiple-access expandable gateway (MEG) frame just before both were sent to seafloor (on 23 August 2000). ROV = remotely operated vehicle, UMC = underwater mateable connector.

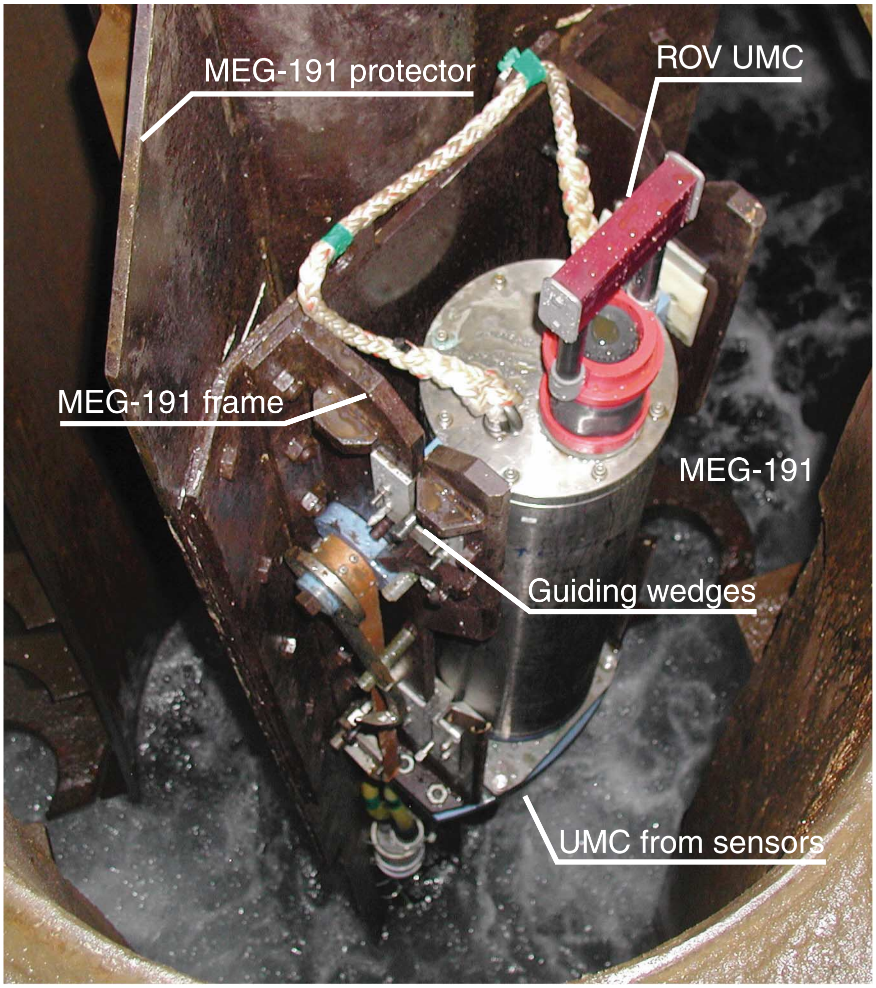


Figure F19. Example showing the results of the time difference measurement of the precision real-time clock (RTC) in the multiple-access expandable gateway (MEG) and the storage acquisition module (SAM). The offset of the RTC in the SAM-191 to the Global Positioning System (GPS) was measured and reported by the combiner/repeater module processor. The time difference between the RTC in the MEG-191 and that in the SAM-191 was also plotted. The time difference is measured using stream sync in a serial line.

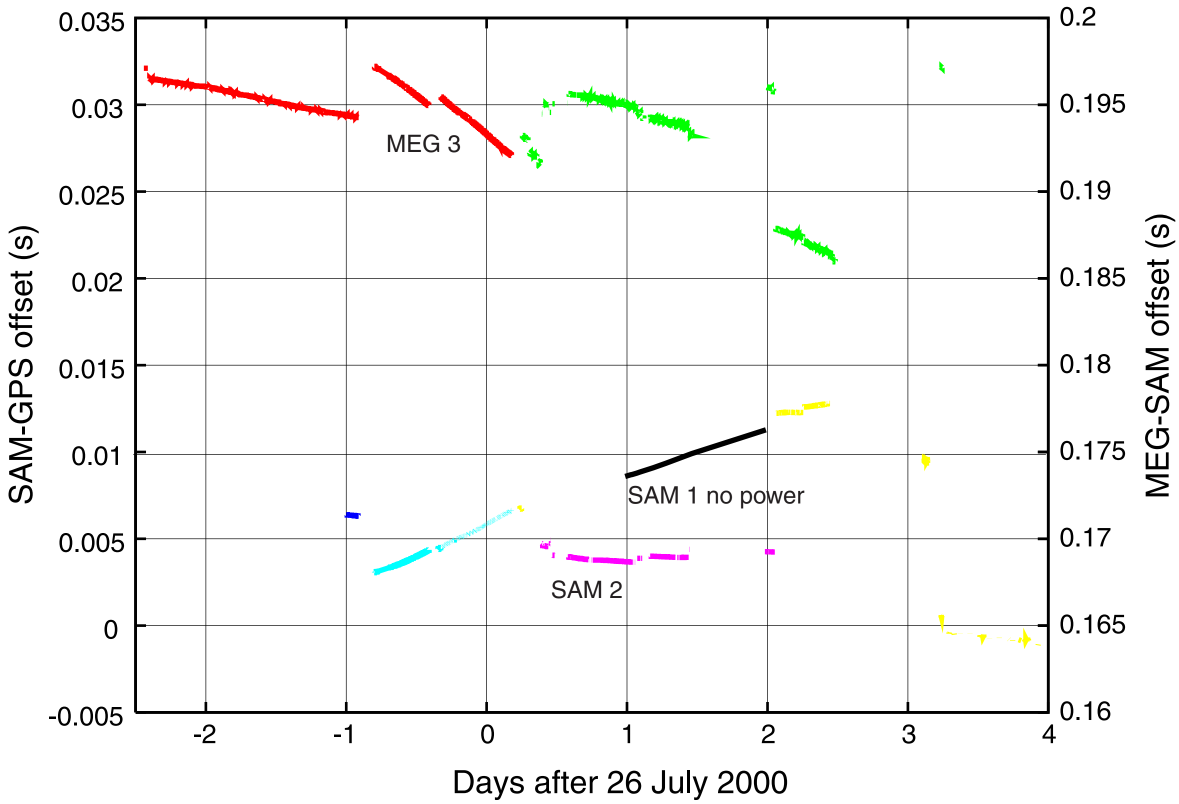


Figure F20. Schematic diagram of the seawater battery (SWB) system. The SWB system consists of four SWB-1200 cells, a canister containing the 24-V DC/DC converter and the power control system (PCS), and the canister of the accumulator and the data logger (DL). The DL is connected to the PCS using an underwater mateable connector (UMC). The PCS can be accessed using a remotely operated vehicle (ROV) when the DL is disconnected. CF = compact flash, Rx = receiving line, Tx = transmitting line.

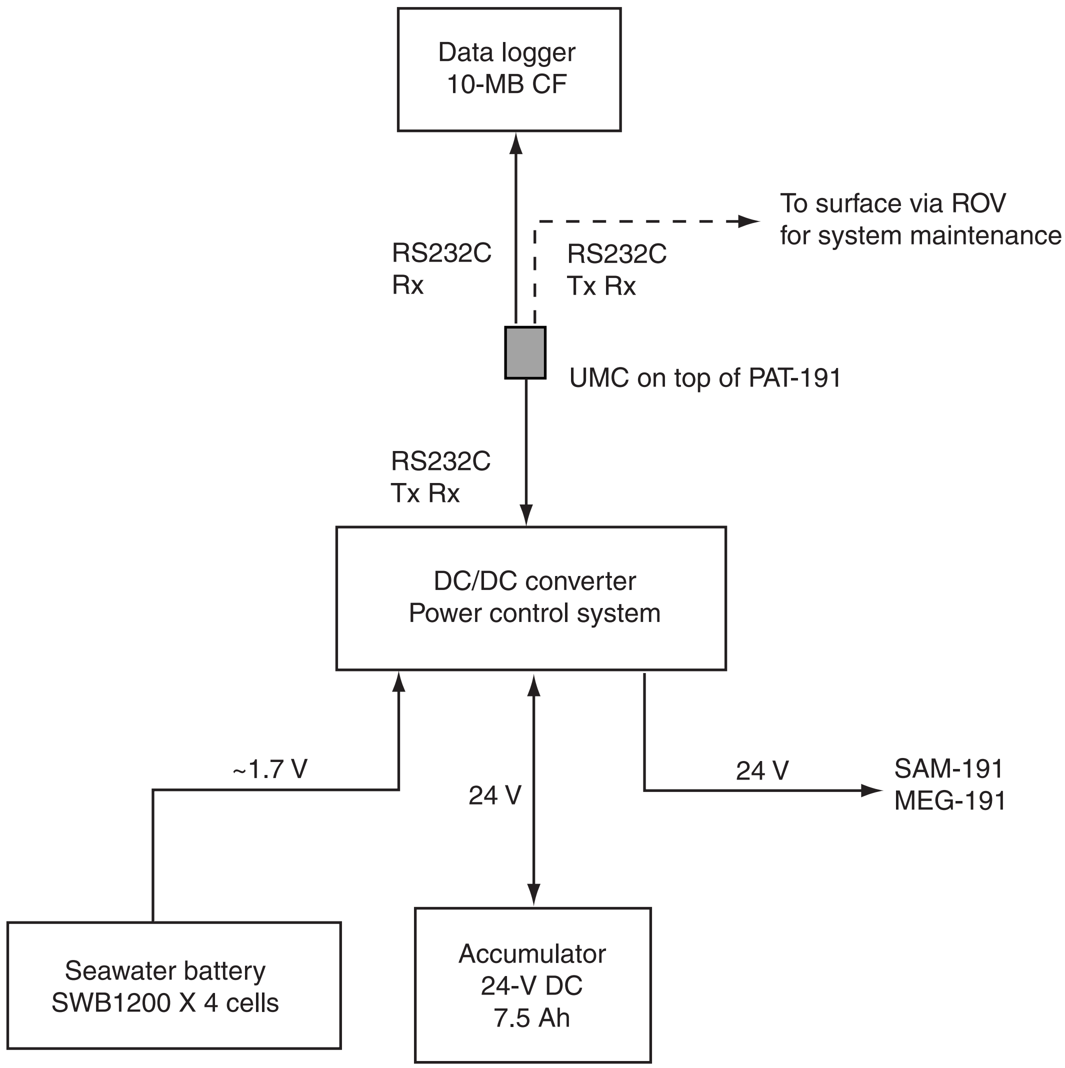


Figure F21. Seawater battery (SWB) cell structure. Modified from Sacks, Suyehiro, Acton, et al., 2000.

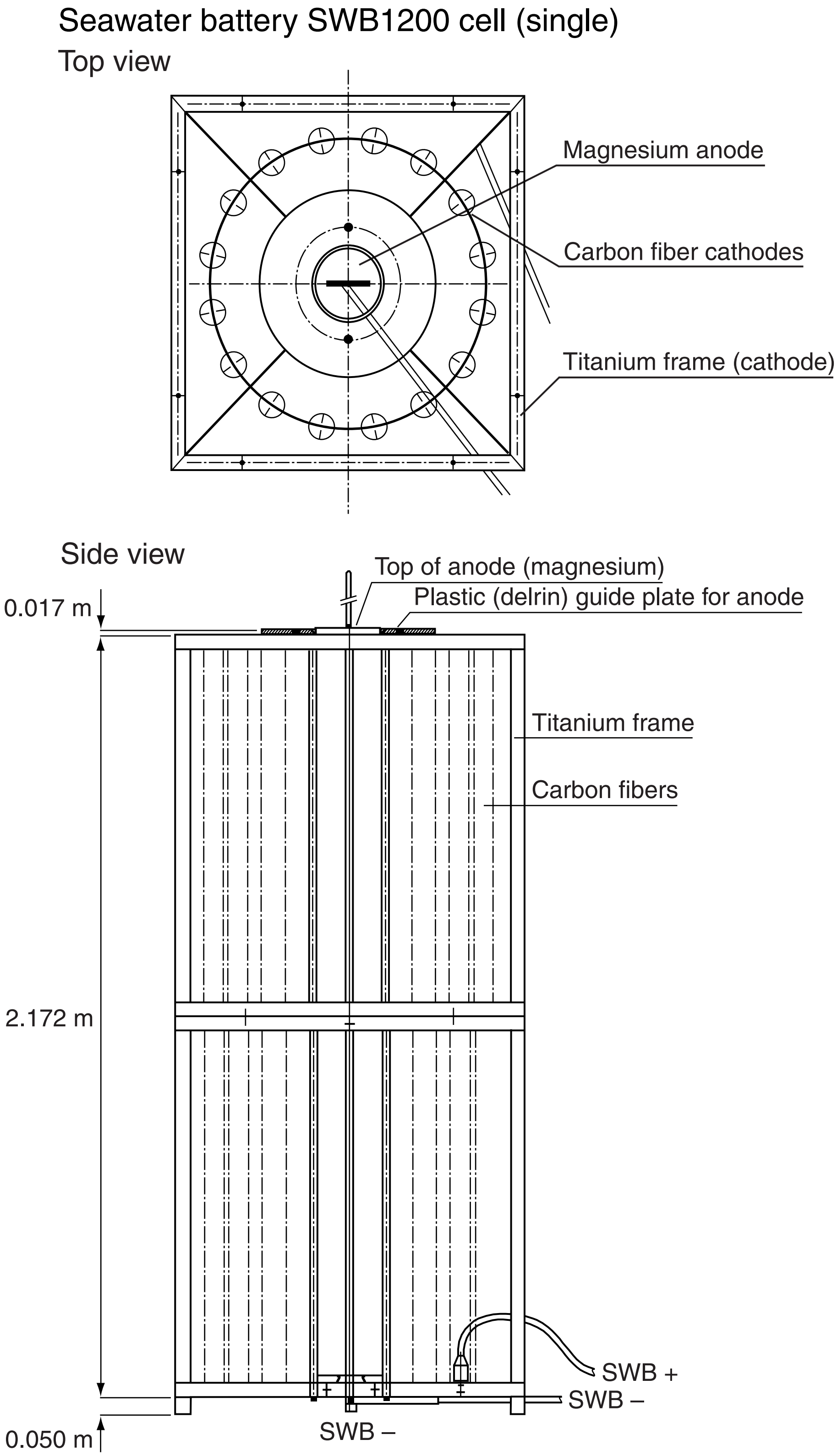


Figure F22. Structure of the carbon fiber brush used in the cell cathode. Modified from Sacks, Suyehiro, Acton, et al., 2000.

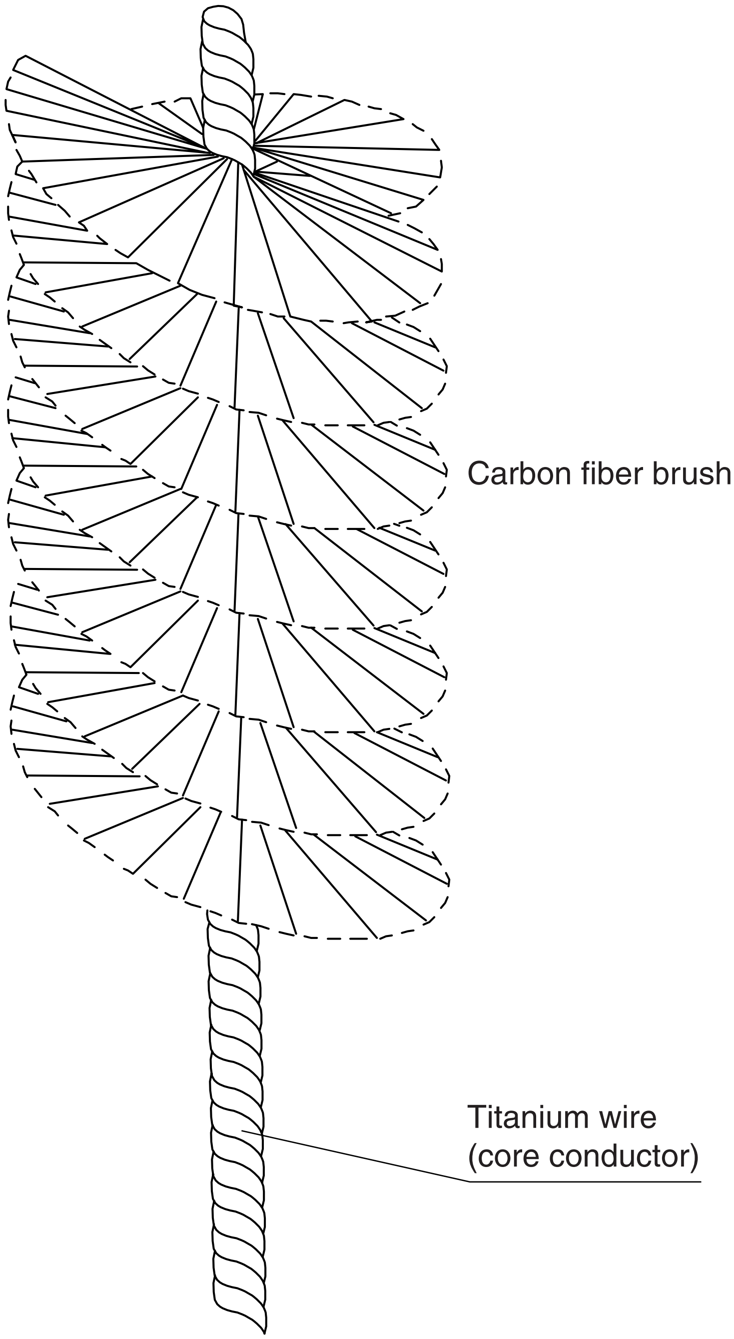


Figure F23. Block diagram of the power control system (PCS). The PCS consists of the interface board, the microcomputer, the DC/DC converter, and the backup battery. The PCS controls the power to the SAM-191 and the MEG-191. SWB = seawater battery, Power SW = power switch, Control SW = the microprocessor controls the switch.

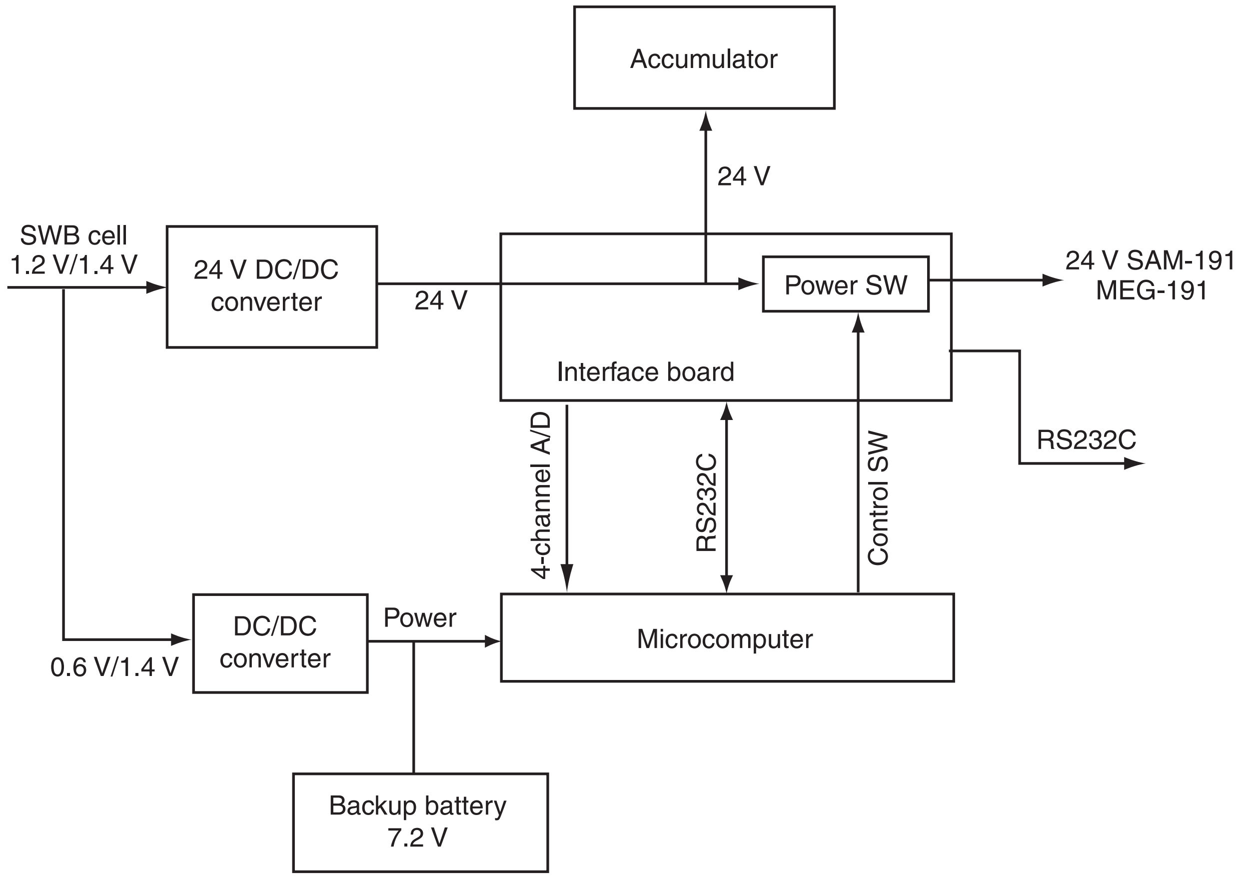


Figure F24. Voltages and currents measured by the power control system (PCS). The voltages are directly measured by an A/D converter on the PCS. The current is estimated by measurement of the voltage drop of a resistor with a small value, which is serially connected to the power line. SWB = seawater battery, Power SW = power switch.

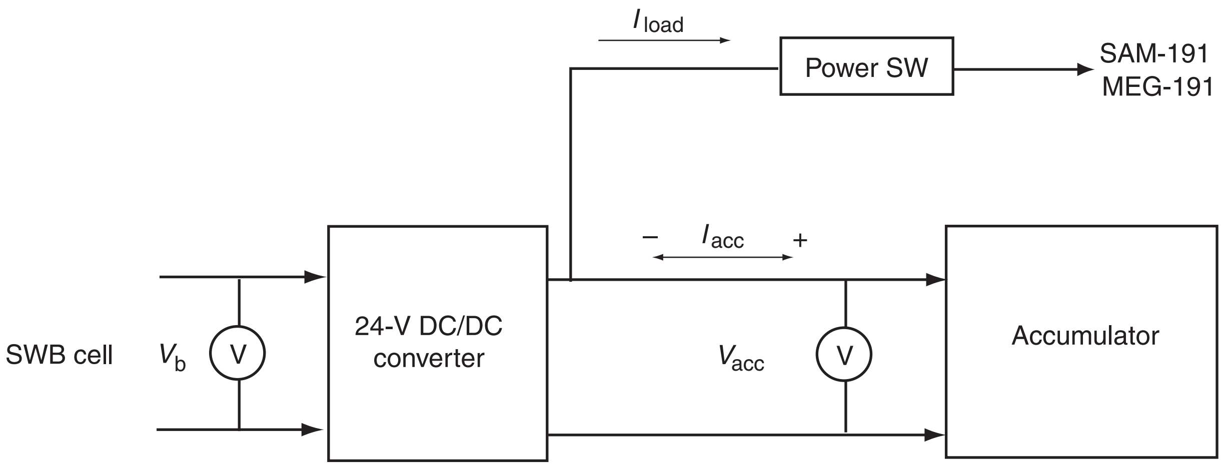


Figure F25. Variation of voltages and currents in the seawater battery system at a test before Leg 191. The power control system (PCS) makes the power switch turn off when the voltage of the accumulator is <20.8 V for ~26 hr. After charging the accumulator, the power switch is turned on because the voltage is >26.5 V. The data were collected by the PCS and were stored in the data logger.

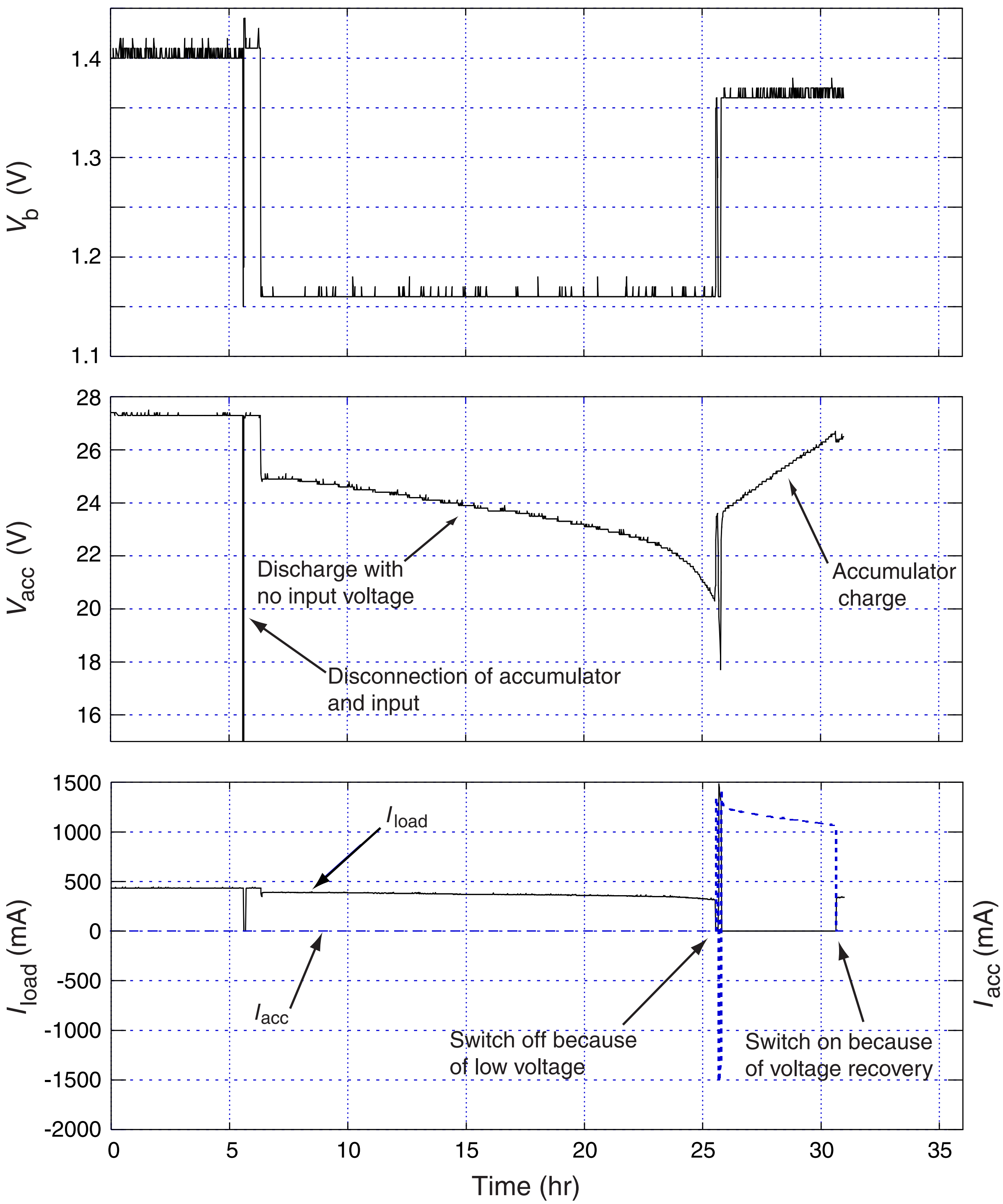


Figure F26. Records from the power control system during the final equipment test. The data were stored in the data logger. During this test, the low-voltage, high-current DC power supply was used in place of the SWB-1200 cells. SAM = storage acquisition module, MEG = multiple-access expandable gateway, OBH = ocean borehole seismometer.

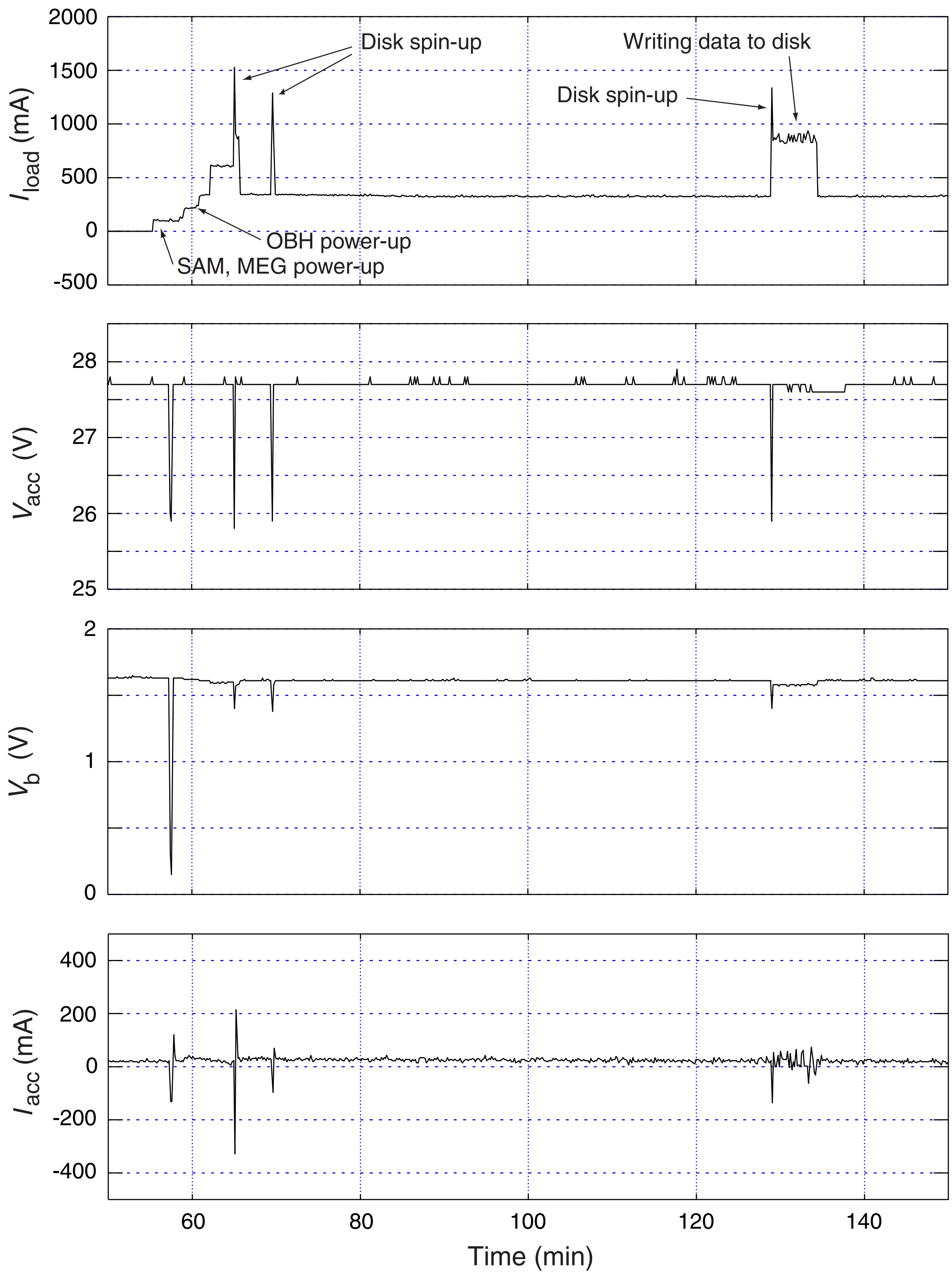


Figure F27. Photograph of the power access terminal in the moonpool area. From Sacks, Suyehiro, Acton, et al., 2000.

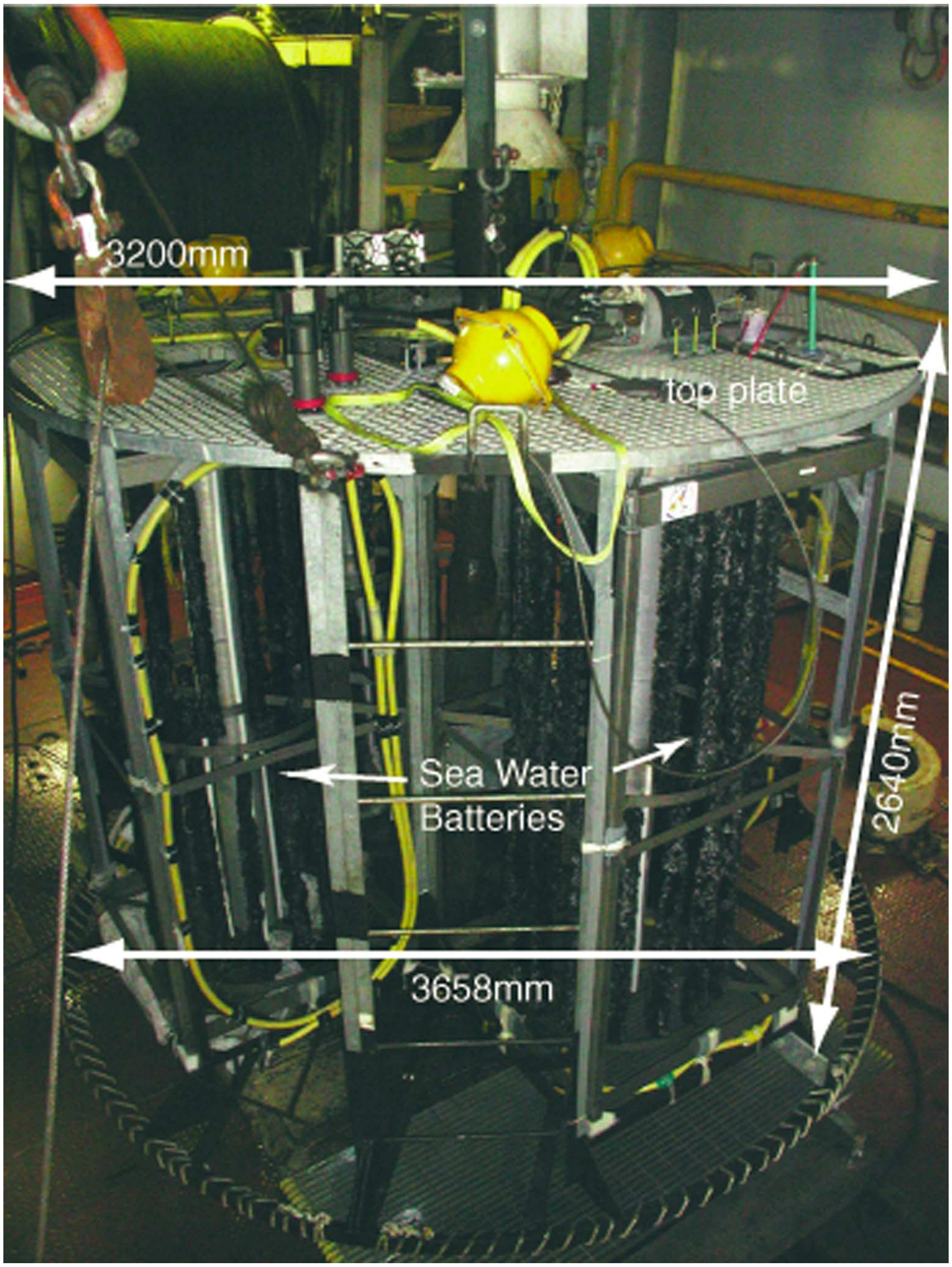


Figure F28. Photograph of the recorder frame of the storage acquisition module (SAM) with a SAM dummy cap. The recorder frame has a mechanism ejecting the SAM-191 by pulling the remotely operated vehicle (ROV)-operated lever. UMC = underwater mateable connector, DL = data logger.

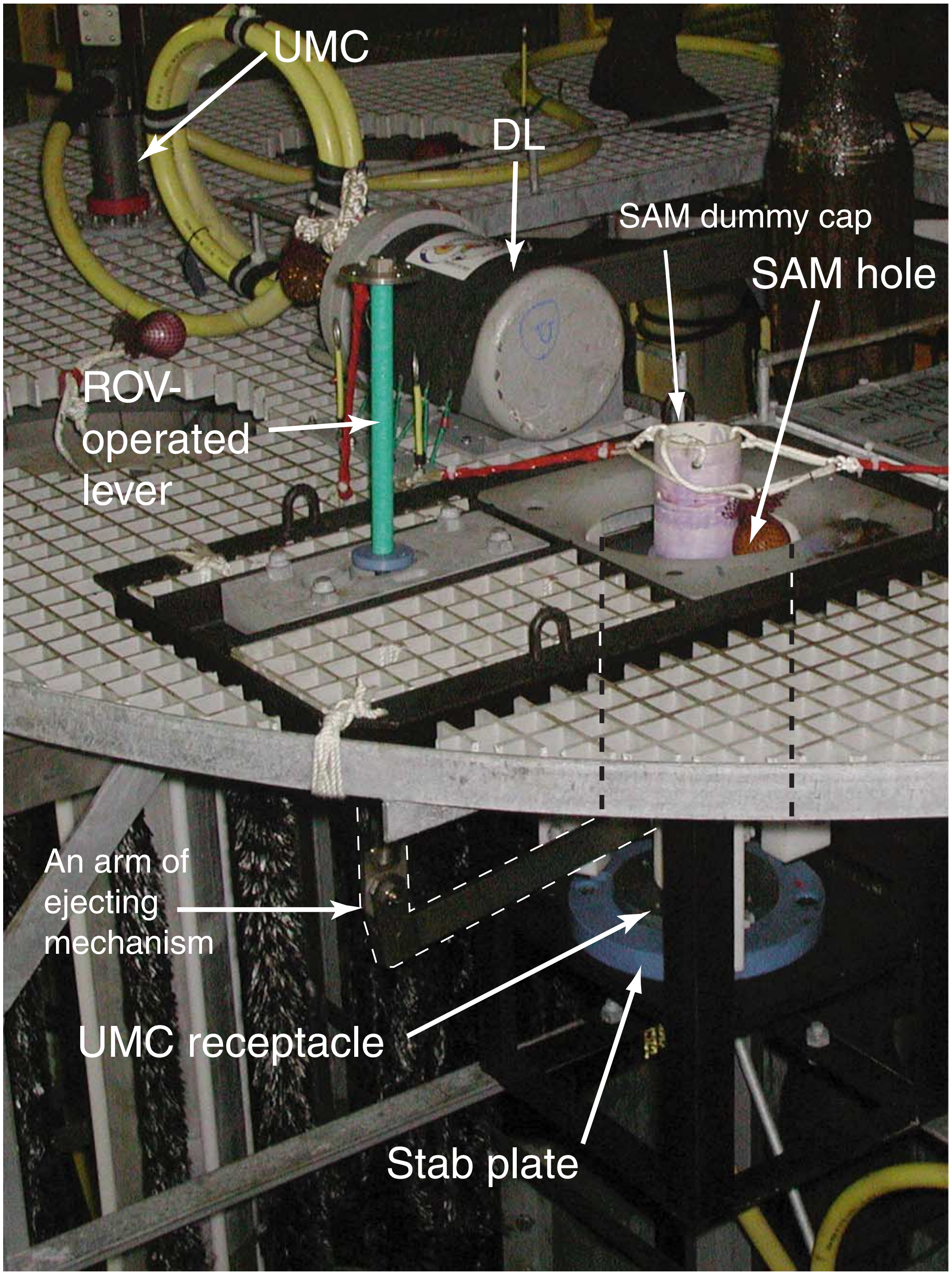


Figure F29. Photograph of JAMSTEC's remotely operated vehicle (ROV) *Kaiko,* which activated the NERE-ID-191 system of the WP-2 observatory. All seafloor assembly electrical connections, the data storage unit, and the data handling and control unit can be removed and replaced by the ROV. The *Kaiko* visited Site 1179 on 29 October 2000 to activate the WP-2 observatory.

Table T1. Glossary of the NEREID-191 system.

Term	Definition
BIA	Borehole instrument assembly, commonly known as the Christmas tree.
CRM	Combiner/repeater module. This is a part of the MEG-191.
DL	Data logger for the PCS in the SWB. It records the condition of the SWB system and is recovered by an ROV or submersible.
DM24	Digitizer module consisting of a 24-bit analog-to-digital converter and microprocessor.
GCF	Guralp Compressed Format, used for data transmission and receiving on an RS232C serial line.
MEG-191	Multiple-access expandable gateway, commonly known as the G-box. It serves as the control unit for power, signal, and timing.
OBH	Ocean borehole seismometer. Modified version of the feedback-type broadband seismometer (Type CMG-1T) made by Guralp Ltd., United Kingdom.
PAT	Power supply access terminal, commonly called the battery frame. It contains the SWB system and SAM-191 and also serves as an ROV or submersible platform.
PDM	Power conditioning/distribution module contained in the MEG-191.
PCS	Power control system. This monitors the condition and control output of the SWB system.
PCB	Printed circuit board.
ROV	Remotely operated vehicle.
RTM	Real-time module, contained in the CRM.
SAM-191	Storage acquisition module. This is a seismic data recorder that can be recovered by an ROV or submersible.
SWB	Seawater battery system, developed by Kongberg Simrad Ltd., Norway, consisting of cells, a DC/DC converter, the PCS, an accumulator, and the DL.
UMC	Underwater mateable connector, produced by Ocean Design Inc., U.S.A.

Table T2. Mapping between sensor channels and stream identification in Guralp Compressed Format.

Sensor channels	Stream ID
Upper seismometer CMG1T T1036:	
Vertical (20 Hz)	d415z4
Vertical (100 Hz)	d415z2
Horizontal N-S (20 Hz)	d415n4
Horizontal N-S (100 Hz)	d415n2
Horizontal E-W (20 Hz)	d415e4
Horizontal E-W (100 Hz)	d415e2
Vertical mass position	d415m8
Horizontal N-S mass position	d415m9
Horizontal E-W mass position	d415ma
Temperature	d415me
Lower seismometer CMG1T T1037:	
Vertical (20 Hz)	d416z4
Vertical (100 Hz)	d416z2
Horizontal N-S (20 Hz)	d416n4
Horizontal N-S (100 Hz)	d416n2
Horizontal E-W (20 Hz)	d416e4
Horizontal E-W (100 Hz)	d416e2
Vertical mass position	d416m8
Horizontal N-S mass position	d416m9
Horizontal E-W mass position	d416ma
Temperature	d416me

Table T3. Explanation of status messages from the combiner/repeater module in the MEG/SAM.

Readout	Explanation
Internal clock 1,113,125 μs fast	CRM internal clock offset over its reference. In the example, the CRM internal clock advances 1,113,125 μs to the reference.
2000 Aug 5 10:30:00 o/s = –6954782 drift = –68	Date/time (year month day hour:min:second), the internal clock offset (o/s) in a unit of 25/1536 (= 1000/1024/60) μs in a fraction of a second and the clock drift over a minute in the same unit as the offset.
Power 28,103Asecs 18.767Asecs 312mA 7.26W	MEG and OBH power consumption, including ampere seconds since the system was started, ampere seconds, average current, and power consumed in the last minute.
Temperature 25.37°C	Temperature in the MEG canister measured on the PDM board.
MIN MAX AVG STATUS #Blks #Naks Pkt# Space	The next three lines summarize the status of OBH power and the data link. The first single-digit number in each line indicates the PDM channel that corresponds to the measurement. Channel 0 is dedicated to SWB voltage measurement. Channels 1 and 2 are dedicated to the OBHs. Channels 3, 4, and 5 are available for connection to internal DM24s (not set in this example).
0 23.25V 23.30V 23.27V SWB high 49 0 28 511	SWB voltages (PDM channel 0) in the last minute, in order of minimum, maximum, and average, respectively. Comparison of these results with thresholds is given as follows: “high” = exceeding the higher threshold, “good” = between the two thresholds, and “low!” = below the lower threshold. The next four readings indicate the number of GCF blocks sent in the last minute, the number of error blocks (NAKs) in the transmission, the last GCF block sequence number, and the available space in the CRM buffer, respectively.
1 136.1mA 144.8mA 140.6mA ON ok 21 0	One-line summary of supply current and data link status for the first OBH sensor. A one-word diagnosis is given with each measurement similar to the SWB voltage measurement example in channel 0: “ok” = between high (160 mA) and low (40 mA) current thresholds, “low” = below the lower threshold, and “leak?” = higher than the upper threshold.
2 142.8mA 149.1mA 144.7mA ON ok 28 0	One-line summary of supply current and data link status for the second OBH sensor.

Notes: CRM = combiner/repeater module, MEG = multiple-access expandable gateway, SAM = storage acquisition module, OBH = ocean borehole seismometer, PDM = power distribution module, SWB = seawater battery system, DM24 = modular digitizer, GCF = Guralp Compressed Format. The SAM status message includes the current measurements of PDM channel 1 (logic supply for the disks), channel 6 (5-V supply for disks), and channel 7 (12-V supply for disks). A status message from the CRM in the SAM includes an additional 100-byte string: Writing 9|3827: Reading 6|4032 Bad Flash 0 1. This line indicates the status of buffer memory: the number of chip and block currently writing and reading and the number of error in writing and reading, respectively.

Table T4. Available command set in the CRM, OBH, and SAM. (See table notes. Continued on next page.)

Command	Definition
CRM available command set:	
ok-1	Enable FORTH vocabulary
.bauds	List baud-rate settings for each serial port
streams?	List all streams and port numbers being received in format: StreamID SystemID Port#
open *sysID strID*	Open other system terminal by pass-thru
(head 4 characters)	
close	Close the pass-thru terminal link
.ids	Show what instrument(s) are currently being talked to
time set-rtc	Set real-time clock for time stamp in format: *yy mm dd hh mm ss*
@rtc.rtc	Fetch real-time clock setting and print
port# baud# baud	Change baud rate
id set-id	
re-sync on	Resynchronize clock to Global Positioning System
auto-trim	Trim the clock start
interval on	Disable auto-calibration
n install	Add the channel for control and monitoring
n remove	Remove control and monitoring
n disable	Switch off the channel and prevent further operation; monitoring is not affected
n enable	Reenable switching on
n power-up	Switch on the channel—if not disabled
n power-down	Switch off the channel
time wake-up	Set start time in format: *mm dd hh mm*
sleep	Switch off the system using watch-dog reset
.limit	Display setting in the units shown in the status block
vl vh ch set-limits	Set limits of power control; *vl* = switch off voltage, *vh* = high limit, and *ch* = channel of PDM
.st	Status reading from power distribution module
.boot	Display last reboot
run-hours?	Show time since last boot
.mean	Show mean voltage of power supply
running?	Show running status
bad-match ?	Display how many more consistent clock measurements are necessary to resynchronize
trm-trim ?	Display a number for clock trim in the backup memory in the power distribution module
phase	Show the clock status
.pwm	Show the clock offset and drift
reminder	Set the clock into timer mode (set a maximum off time of 10 min)
manual	Start the system in timer mode
8 watch +!	Switch on monitoring
–8 watch +!	Switch off monitoring
ch remove	Stop switching and monitoring of the channel (e.g., pmd)
ch disable	Stop switching only—status will still be displayed
o/p ?	This should show zero (i.e., no task currently outputting to the display/status)
0 0 o/p 2!	Manually reset the semaphore
set-clock	Set backup real-time clock
rtc>sam	Set real-time clock into internal clock (MEG, SAM)
.int	Display internal clock
master-sync	Set internal clock (and backup real-time clock) to the RTM time
2400 /sci2	Set baud rate of the GPS serial port to 2400 bps for accessing the RTM
4800 /sci2	Restore baud rate for GPS connection
rtm-open	Enable access to the RTM module
rtm-close	Disable access to the RTM module
+1ppm	Change the frequency of the RTM (precision clock)
–1ppm	Change the frequency of the RTM (precision clock)
cancel	Restore the module to normal state using the calculated trim value
n faster	Change the RTM frequency by *n* ppm
n slower	Change the RTM frequency by *n* ppm
n enable	Request *n* channel makes enabled (for a shutdown channel)
Ref-clk +time	Increment internal clock by 1 s
–1 ref-clk 2+ +!	Decrement internal clock by 1 s
Re-sync on	Enable resync to reference (resync requires 15 min of mismatch)
Auto-trim on	Allow trimming of real-time module to reference time
Rtm-trim ?	Report total trim value
1 sync-on	
n gps-type	*n*; 2-GARMIN, 3-Stream sync
time-ref ?	Restart synchronization
configuration show	
sync-src ?	See settings by GPS-type commands
.ext	Show external clock
/uarts	Initialize UARTS
n activate	Enable serial port #*n*

Table T4 (continued).

Command	Definition
n rate baud re-boot	Change baud rate (*n* = port #, *rate* = baud rate)
OBH available command set:	
date d-day	Set deploy date in format: *day month year*
.d-day	Show deploy date setting
Mpos *n* dump	Hex dump first *n* mass positions (each 2 bytes)
Mpos ?	Request mass position of Z
Mpos 2 + ?	Request mass position of N-S
Mpos 4 + ?	Request mass position of E-W
Masses?	Show mass positions continuously (type any key to stop)
.soh	Request ocean borehole seismometer health status
SAM available command set:	
2 ~protect	Disarm protection of the flash memory
save-cmos	Save CMOS memory in EEPROM
dir	Display directory of the HDD records
chunk?	Check number of memory chip installed; 1 chip = 4 MB
target#?	Show current target HDD
n target	Set current HDD.flash
chk-disc	Spin-up current disk
stop-unit	Spin down
Reset-disc	Initialize current disk
Next-target	Increase SCSI ID of HDD
0 erase-card	Erase the whole card
0 erase-chip	Erase specified chip: 0–15, 4 MB each
/flash#	Reset the pointers to 0|0
2 /chunk	Change number of chips for buffering (2–14); maximum is 14 to allow time for disk operation
Disc-off	Spin-down HDD
2 ~protect save-cmos	Copy entire CMOS to EEPROM
.d-day	Show deploy date setting

Notes: CRM = combiner/repeater module, OBH = ocean borehole seismometer, SAM = storage acquisition module, GPS = Global Positioning System, MEG = multiple-access expandable gateway, RTM = real-time clock, HDD = hard disk drive. Italics denote variables in the command string.

Table T5. Pin assignments of underwater mateable stab plate connectors.

	Connection of downhole cable				Connection inside of MEG	Connection inside of OBH		
Function (OBH)	Connector for OBH (MSSK-8#20-CCP)	Seacon blue cable	Neutral buoyancy cable	UMC pin/A,B	MEG D-sub9 (for OBH)	OBH D-sub15	Cable inside of OBH	Connector of OBH (Seacon MSSK-8#20-BCR)
Power +Vin	1	Brown	Red/in	1/A	8 (red)	8	Red	1
0Vin	2	Gray	Black/in	2/A	9 (green)	7	Green	2
0Vin	3	White	Blue/out	2/B	9 (green)	7	Green	3
Signal GND	4	Yellow	Green/out	1/B	5 (black)	9	Black	4
Rx(+)	5	Orange	Red/out	3/B	3 (orange)	3	Blue	5
Rx(–)	6	Red	Yellow/out	4/B	4 (white)	10	Pink	6
Tx(+)	7	Blue	Green/in	3/A	2 (blue)	1	Orange	7
Tx(–)	8	Green	Blue/in	4/A	1 (pink)	2	Pink	8

Notes: MEG = multiple-access expandable gateway, OBH = ocean borehole seismometer, UMC = underwater mateable connector. Function abbreviations: Rx = receive, Tx = transmit, GND = ground, Vin = power supply input.

Table T6. Data storage estimation for the NEREID-191 seismic observatory.

Information type	Amount of data
Status information from SAM/MEG	1.31 MB/day (including GCF header)
Seismic data	3 channels × 2 systems × (100 + 20 sps) × 2 bytes (typical) × 3600 s × 24 hr + header = 121 MB/day
Slow seismic data	4 channels (mass, position, temperature) × 2 systems × 4 sps × 1 byte × 3600 s × 24 hr = 2.68 MB/day
Total of 125 MB/day = 590 days to fill 72-GB hard disk storage in the SAM	

Note: SAM = storage acquisition module, MEG = multiple-access expandable gateway, GCF = Guralp Compressed Format.

Table T7. Power consumption of the NEREID-191 system.

Subsystem	Condition	Power consumption (W)
CRM		0.73
OBH	Mass locked, short cable	2.7
	Mass unlocked, short cable	2.5
	Mass unlocked, measured at PDM	3.3
DC/DC for OBH	No supply for OBH	0.3
DM24		1.55
SAM-191	No disk running	1.0
	Disk powered (10 s)	8.16 (10 s)
	Disk spin up	30.98 (maximum)
	Disk write	~14.8 to ~15.8 (variable)
	(average over disk operation period)	(16.9)
	Increase by running GPS receiver	0.15
MEG + 1 × OBH		4.0
MEG + 2 × OBH		7.33
SAM	11-hr cycle average for a typical amount of incoming data: (100 sps + 20 sps) × 6 channels × 2 bytes	1.77
Total average:		
MEG + 2 × OBH + SAM		9.1

Note: CRM = combiner/repeater module, OBH = ocean borehole seismometer, DM24 = modular digitizer, SAM = storage acquisition module, MEG = multiple-access expandable gateway, PDM = power distribution module, GPS = Global Positioning System.