EXtreme ecosystem studies in the deep OCEan:

Technological Developments

Deliverable 3D1
Detailed specification of chemical analyser, water sampler, methane and flow sensor.

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WP3 In situ sensing, analysis and water sampling (E. Sauter)

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Content

Work Package Summary

WP3.1. Specifications of the in situ flow analyser 1
WP3.2: Specifications of the small volume multi water sampler 5
WP3.3 In situ sensors - Approaches to increase the sensitivity of underwater methane sensors 8
WP3.3 In situ sensors - Optimisation of a hot film sensor 10
**Work Package Summary**

WP 3 focused on the integration and modification of existing underwater instrumentation, with the aim to provide efficient and reliable payload for stationary deep-sea observatories and moving underwater platforms (i.e. ROVs, AUVs, and submersibles).

Within the three subunits, specific types of instruments were further developed:

- WP3.1 In-situ flow analysis (P#1, P#12)
- WP3.2 Small volume multi water sampler (P#1, P#2)
- WP3.3 In situ sensors: underwater methane sensor (P#2, P#13, subcontr. of P#2) and hot film flow sensor (P#7, P#1)

In accordance to the only Deliverable 3D1 within the reporting period, emphasis was placed on the technical specification of the instruments to be modified during the first year of EXOCET/D. To fulfil this task, contact was intensified via email and phone conferences but also by several informal working meetings organised in Toulon, Brest, Trittau and Bremerhaven. First order design and constructions were worked out (by means of CAD tools) and discussed iteratively to take scientific, size and user requirements into account right from the start of the work. Technical specifications of the instruments were also specified in respect to an increased interoperability between the various platforms and instruments projected in WP5.

**WP3.1. Specifications of the in situ flow analyser**

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Within this WP, Ifremer is responsible for the development of a new in situ chemical analyser. Taking advantage of the expertise gained by Ifremer during the development and scientific use of the ALCHIMIST (chemical analyser for *in situ* measurements, Le Bris 2000) a second generation *in situ* chemical analyser based on flow analysis and colorimetric detection will be developed. The design will be based on microfluidic and miniaturised photometric detection systems. Development aims at:

- increasing measurement reliability, and the frequency of analysis in order to respond to steep water column gradients,
- minimising power and reagent consumption and inhibiting fouling processes within flow-through parts of the system.

Efficiency and reliability tests of the autonomous analyser will be performed in the field by implementation on a long-term benthic station as well as on an underwater vehicle. The final objective is the use at the end of the project of a colorimetric *in situ* flow analyser (3 parameters e.g. sulphide, iron II and iron II+III) using microfluidics and miniaturised detectors.

Figure 1. The in situ chemical analyser ALCHIMIST implemented on the ROV Victor 6000, Victor first cruise.

Concept:

The concept of the design is focussed on an integrated device built around electronic, optical and hydraulic subsystems potentially interesting for other flow systems (e.g. sampling or in line measurement for the methane sensor). These subsystems will use, whenever possible, industrially
available elements, taking into account their cost and obsolescence. The main criteria driving the final choice of these elements are: reliability, performance, size, consumption and cost.

1. Development and specifications of the CHEMINI module

The specifications and state of the project that drive the final design are listed below:

An analyser is a sensing element: a mono parameter in situ chemical analyser will be assimilated to a sensing element in the EXOCET/D systems. Several advantages are arising from this concept, the ability to make simultaneous measurements, the independence of each measurement, a reliability increase, the possible use of different detection methods, the modularity of the system (1, 2, 3 or more parameters). The analysers will be set serially on the sampling line and controlled by a single software.

The design will focus on the overall dimensions and ergonomics of the device to define if the hydraulic part (equipressurised tank) must be associated to the optical and electronic parts (in a pressure tank). The two part solution appears to be ideal, in terms of implementation on submersibles and at sea maintenance. A design with a unique part will be available for cost and industrial evaluation.

The flow manifold will be engraved in PMMA. The components (pumps and valves) will be integrated directly on the manifold limiting the tubing's and connecting parts. A multiway valve connector will allow a fast and easy connection of the reagents and standards to the engraved manifold.

The valves that will be used are coming from Lee Company, serial LFR. There are chemically inert, small sized and easily mounted on the engraved manifold. Their functioning has been validated in equipressure in oil (Fluorinert FC 77) without modifying the valve, at ambient temperature and also at 6°C. The peristaltic pumps were furnished by Meredos and have been modified to work in situ. The modified pump gives adequate flow rates at up to 6000 m (working depth).

The dual wavelength detection module based on LEDs is developed by Ifremer (TSI/ME) and the society Micro Module.

The flow cell will be designed in quartz (optical quality) and subcontracted to the society HELMA. The use of quartz introduces high security constraints, the security coefficient to be tested is 3 instead of 1.2. A specific pressure tank working up to 2000 bars is being built to perform the pressure test on the flow cell. To limit the risk, two working pressure will be tested: 300 and 625 bars.

The electronic part of the system is developed in Ifremer TSI/ME department around the board ATMEL Atmega. This is a low consumption board compatible with a use on an ASSEM node in order to ease the final tests without any connector to plug on and off. This board is equipped with the Bluetooth technology allowing wireless communication to a PC or a PDA.

Four analysers will be developed during the EXOCET/D project: three identical prototypes CHEMINI by Ifremer and one new DPA by SYSTEA.

The chemical parameters to be measured are total sulphide (ΣS), iron II, total iron (FeII + FeIII). The analytical methods based on colorimetric detection have been extensively studied at Ifremer both in the lab and in situ. The definition of the manifold to be engraved will be done by DEEP LEP and followed by a validation step.

Other parameters are envisaged and the analysers will be versatile for existing chemical analysis methods (nitrite, nitrate, phosphate, silicate, pH…) and open for new developments.

Expected performances are resumed in the following table:

<table>
<thead>
<tr>
<th>Table 1. Expected performances of the future CHEMINI analyser</th>
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<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>Detection limit (µM)</td>
</tr>
<tr>
<td>Accuracy (%)</td>
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<tr>
<td>Time of analysis (s)</td>
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</table>
The CHEMINI new generation of chemical analyser will be able to work with the various principles of flow analysis (FIA, CFA, stop flow, ...). SYSTEA will address the μLFA stop flow method.

SYSTEA will address the cost effectiveness of the methods and technical choices. They will evaluate the industrial potential of the analysers.

A thermostated manifold is not necessary for the analysis of the 3 defined parameters. However, the electronic board will be able to control it in case of other analytes. The analyser will be equipped with an internal pressure sensor.

Each CHEMINI analyser will be able to perform a selection between 6 ways (samples or standards).

The CHEMINI analysers will be programmed and controlled by a home made software through an IHM. This software will allow the simultaneous control of at least 3 analysers. The software will be built in 2 levels:

a) In the low level (control mode), the user will have an access and control to all the elementary actions of the analyser. The IHM will give a graphical view of the status of the individual parts of the analyser. The data will be stored in a format compatible with Excel. The elementary actions are presented in the following table:

<table>
<thead>
<tr>
<th>Element</th>
<th>Action</th>
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<tbody>
<tr>
<td>pumps</td>
<td>On/off</td>
</tr>
<tr>
<td>valves</td>
<td>On/off</td>
</tr>
<tr>
<td>detector</td>
<td>On/off</td>
</tr>
<tr>
<td>thermostat</td>
<td>On/off</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Action</th>
<th>Direction</th>
<th>Speed</th>
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<table>
<thead>
<tr>
<th>Action</th>
<th>Frequency</th>
<th>Range</th>
<th>Intensity</th>
<th>Acquisition</th>
<th>Auto</th>
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<table>
<thead>
<tr>
<th>Action</th>
<th>Value</th>
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</table>

b) In the second level (running mode), the user will be able to program and store automatic sequences and cycles, the sequences and cycles being launched either by the user in a teleoperated mode, either by a "master automate" in a semi autonomous mode. The sequences and cycles are stored in text files. The IHM provides an access to the control action of the analyser: selection of the sequence and or cycle, launching and stop of the cycles, graphical visualisation of the detector response, graphical visualisation of the previous analysis performed within the same cycle, choice of the calibration file. The data treatment will be programmed in this window (acquisition frequency, acquisition window, calculation of k0). A calibration mode will provide the possibility to build calibration curve from injections of standards. These calibration curves will be stored in text files and used in real time to transform the absorbancies in concentration.

![Figure 2. The CHEMINI new generation of chemical analyser will be able to work with the various principles of flow analysis. It will be programmed and controlled by a home made software that will be built in 2 levels illustrated here.](image)

The development of a fully autonomous version will not be performed in the Exocet/d project. The running of the analysers will be done either in a teleoperated mode on an ROV or in a semi autonomous mode mastered (operation, data storage and energy) by an ASSEM like electronic...
system (COSTOF). The electronic board will be able to store locally 700 spectrums at 2 wavelengths.

The demonstration action (MoMARETO cruise) of the Exocet/d project will be held in an hydrothermal area at 1600m depth. The analysers will be implemented on the ROV Victor and on an ASSEM like structure. The implementation step will be done in collaboration with P. Siméoni and J.F. Drogou (Ifremer, DNIS, WP5) and J. Blandin (Ifremer TSI).

The development time table will be decided after the specification step. This time table will take into account the different steps of design, accomplishment, test and validation of each subsystem up to the final prototype.

The collaboration between Ifremer and SYSTEA (partner 12) will focus on the comparison of two different approaches (µLFA from SYSTEA vs. FIA from Ifremer) to analyse the three studied parameters. This comparison could lead to a transfer of technology between Ifremer and SYSTEA during the project (analytical protocols, hydraulic module, electronic board, detector,...).

2. Development and specifications of the µLFA module

Beside the development and specification of the FIA module CHEMINI, an in situ micro loop flow analyser (µFLA) is developed which bases on the stop flow method. Research activities carried out by SYSTEA during the first year of EXOCET/D are briefly reviewed as follows.

These research activities mainly aimed at

- defining the analytical methods and detailed technical specifications for the new measuring device, in strict co-ordination with Ifremer partner. The analytical multiparametric module will measure sulphide, iron II / III and it will be used in sequential multiparametric or in a new fast measuring mode on a single parameter selected between the three available. The device will be designed to be used with both the ROV and the deployable long-term measurement node. The maximum care will be spent to allow the highest reliability and an easy maintenance on field. Even if proprietary analytical technology \( \mu \text{LFA} \) (micro Loop Flow Analysis) will be used, we will try to ensure the highest level of mechanical and electric compatibility with the Ifremer Chemini analytical module

- performing an extended analysis of the performance of our commercial probes actually used at Ifremer, to identify upgrades to be implemented on the new system, to enhance system reliability and easy maintenance. A technical meeting was convened in Boulogne and Argenton to visit the sites where SYSTEA's NPA probes are located, inside Ifremer Marel buoy systems.

- improving and testing specific components to be used on the new measuring module. A new integrated Plexiglas manifold was designed and developed to allow an higher level of integration of the hydraulic actuators. A new gear pump was selected, coupled with an OEM motor and extensively tested. Two types of colorimetric flow-cells with heating capability were designed and tested on field conditions (overpressure up to 3 bars): stainless steel and Plexiglas type. A new hardware control system to perform a software automatic zeroing of colorimetric signal was developed and tested.

- identifying the layout of a new control system that will reduce the size of the device and ensure the low consumption of power supply requested. A commercial series of microcontrollers were selected. These devices have the capability to manage on board the I/O actuators and the necessary A/D and D/A conversions requested to manage the analytical devices, using a software platform compatible with the actual firmware used in SYSTEA's commercial probes

- studying and performing a preliminary design of the firmware and protocol upgrades necessary to improve the new electronic control system and to allow the easiest handling of the system with the ROV and the long-term measuring module.

- developing some new functions on standard firmware and software, which will be propedeutic for the use with the new experimental measuring module.
A certain number of compatibility issues with Ifremer analytical module were discussed and identified:

- same or at least similar analytical and electronic external containers;
- same of similar types of hydraulic valves, already tested to be used in the required oil pressure compensation layout;
- same type of reagent bags;
- same or equivalent colorimetric analytical methods, according to the requested sample matrix and measuring ranges;
- communication protocol already available for integration with the long term deployable module.

The second year's research activities will mainly aim at:

- **defining another series of items to enhance compatibility and reliability aspects**, like the enhancement and common use of the SYSTEA’ commercial hydraulic multiconnector, to allow quickest reagents substitution on all the analytical measuring devices used inside the research project;
- **studying and designing the new mechanical layout** of the analytical, electronic and reagent modules according to the technical and compatibility specifications already defined;
- **designing and improving the new measuring system**, starting from the standard DPA product licensed by Sysmedia subcontractor, with all the necessary modifications and upgrades required by the specific application;
- **integrating and performing extensive tests** in laboratory of the new measuring system;
- **developing and applying sulphide** analytical measuring method on the μLFA technology, which was developed and published by Ifremer researchers;
- **modifying and testing the iron II / III analytical methods** already used in commercial SYSTEA’s products, in order to be used in the μLFA analytical reactor and eventually to compare them with the Ifremer methods;
- **performing the necessary pressure test** on the new integrated device using Ifremer facilities available in Brest;
- **performing a pool mooring integration test** with the Ifremer long-term deployable monitoring module.

**WP3.2: Specifications of the small volume multi water sampler**

Authors: D. Le Roux, R. Vuillemin, P.M. Sarradin (Ifremer)

Contributors: P. Dorval, M. Hamon, K. Bucas, J.P. Sudreau, L. Bignon, J.F. Rolin, C. Le Gall (Ifremer), E. Sauter (AWI)

As a specific feature of the instrumentation, a small volume multi water sampler **PEPITO** (Small PEP) will be developed. It will combine a high number of water samples within a concise and small instrument. The sampler will be designed to take water samples at certain way points of an underwater vehicle’s course or at programmed time intervals during a stationary deployment. The sampler will provide seawater samples for reference measurements subsequent to the device’s deployment for analyses that can not be carried out in situ as well as for in situ sensor calibration and validation. This will offer the opportunity to complement the range of geochemical species covered by in situ sensors and also to perform reference measurements from water samples as regular in situ calibration ("ground truthing").
The new water sampler is derived from the existing PEP (Préleveur d’Eau par Pompage) implemented on the ROV Victor 6000. The overall dimensions of this original device are: 640*620*480 mm with a capacity of nineteen 200 ml samples. The functioning is based on the single use of two hydraulic activators inducing a high mechanical complexity and no possible control of the position of the sampler (communication).

Figure 3. Top view of the PEP (Préleveur d’Eau par Pompage)

Specifications

The specifications that will drive the final design are listed below. The leading principle is to use whenever possible the same technology and components (pumps, valves, control board) for the analysers and the water sampler.

- The overall dimension of the 3 new analysers CHEMINIs (3 parameters) and the new water sampler PEPITO should be equivalent to the dimension of the actual PEP. For the PEPITO, dimensions are 500 x 500 x 480 mm. Sample as well as reagents volumes for the chemical analysers can not be reduced.
- The sampled volume range between 20 to 2000 ml.
- The new water sampler is equipped with titanium bottles similar to PEP bottles. For samples of 20 ml to 2000 ml the bottle base will be equipped with bag supports. An interface will be defined to receive other storage devices.
- PEPITO is able to take 25 samples (5 rows of 5 samples).
- The filling up of the sample is performed by a peristaltic pump similar to the one developed for the analyser. The flow rate is controlled by software up to 300/400 ml min\(^{-1}\).
- The pump must be able to perform in situ filtration on 0.45 µM filters and to circulate the sample through ion exchange columns. Filters will only be used with bag and filter supports and, will be integrated between bags and bottle base. Filters and filter supports will be supplied by Ifremer/DEEP/LEP.
- The new sampler is able to add a specific reagent (preservative, chemical reagent, ...) to specific samples. This addition could be done by a solenoid pump associated to the sample inlet. We limit the injection to 10 samples, 2 per rows. Injections volumes range between 50 µl to 500µl.
- The duration of the sampling step must not exceed 5 minutes.
- Hydraulic manifold is divided in 5 sampling rows. Each row can be then rinsed independently to minimise rinsing time.
- Hydraulic manifold material will be probably in PEEK. Nevertheless, we will study the possibility of using others materials. It is necessary to verify the chemical compatibility with reagents.
- Actually PEP’s bottle give satisfaction to users. So we keep similar elements to design the new bottle (piston and pipe, materials (PEEK, titanium), seals). The dead volume of PEP’s bottle is very small (about 0,3ml) and this will be kept for PEPITO. The mounting facilities of the bottle will be eased, especially the tap. Only a quarter of turn will be necessary to connect the bottle and to open the tap.
Operated component technology developments are the same for the new sampler and the analysers. Electronic design is also similar for the two devices. Operated components are mounted in a oil tank in equipressure.

Because of the large quantity of operated components (5 x 6 valves and 5 x 2 solenoid pumps, for a total of at least 40 components), several electric connections are needed. There are two possibilities:

a- We will try to put part of the electronics in the oil tank in equipressure so one 8 pins connector is needed or

b- if it is not possible to use electronic card in equipressure, 5 connectors with about 10 pins will be needed (ie one connector per row).

We will develop an interface to adapt one SBSE preconcentrator instead of one bottle.

To obtain equipressure in all parts of PEPITO's sampling bottle during the submersible diving, bottles will be filled with an inert solution. This solution will be emptied with the peristaltic pump before starting the cycle. This operation of filling and emptying will be automated and controlled by the pilot software.

One bottle's interface will be developed to empty the bottle in laboratory for analysis.

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**Conclusion**

This document presents the specifications for the development of the chemical analyser and the water sampler within the Exocet/d project. The next step will be the elaboration of a time schedule that will take into account the different steps of design, accomplishment, test and validation of each subsystem up to the final prototypes.

**Reference documents**

- Exocet/d annex 1
- Report of the EXOCET/D kick off meeting
WP3.3 In situ sensors - Approaches to increase the sensitivity of underwater methane sensors

Authors: E. Sauter (AWI), O. Hach IAE), M. Masson (CAPSUM)
Contributors: M. Schlütter, U. Hoge, M. Gensheimer (AWI), K. Mueller (IAE)

Specification of the tasks

Beside the optimisation of a hot film sensor within WP3.3, a commercially available underwater methane sensor was issued to be further improved in sensitivity and response behaviour. Whereas the sensor was optimised during the ASSEM project in respect to drift stability and energy demands, the aim in EXOCET/D is to end up with a prototype that can be used on moving underwater platforms like ROVs and AUVs. Against these aims the following work units were defined:

- Miniaturisation of the sensor head to lower diffusion times;
- Development of a special flow-through chamber to maintain constant approach flow at the sensor membrane;
- Improvement of the sensor performance through digital signal processing by quantification of sensor dynamics and error sources. The known error will be eliminated by dynamic filters containing a sensor model with suitable cost functions;
- Development of a stable algorithm for the filter and its implementation in a DSP (Digital Signal Processor) or FPGA (Field Programmable Gate Array).

Miniaturisation of sensor head (CAPSUM, P#13, M. Masson)

The original sensor head was redesigned to minimise diffusive transport distances within the sensor. By abandoning the humidity sensor (parameter calculated instead) size was further reduced. By this redesign the sensor’s response and decay times were considerably improved (45 sec and 3-5 min, respectively). To fit the new sensor head, laboratory tests and calibration
chambers had to be modified accordingly. Furthermore tests with new membrane materials and other new experimental parameters have been performed.

Size reduction is limited if the design principles of the existing sensor housing is used. To open alternatives for further size reduction, a new concept of one way sensor heads was discussed. This measure would minimise the occurrence of laminar layers and hydrodynamic dead zones at the membrane that hinder quick turbulent mixing. However, such changes would require a redesign of many sensor components as electronic boards and tightenings and would be a future development beyond the EXOCET/D project.

Figure 5. Original methane sensor (left), different approaches to reduce the size of the sensor head, e.g. by abandonment of the humidity sensor

**Digital in line signal processing (IAE, AWI)**

Although the hardware modifications described above are essential, the operability on moving under water platforms requires even shorter response and decay times of the sensor. System immanent critical steps in respect to reaction time are transport processes as diffusion through the sensor’s membrane and adsorption / desorption at the semiconductor surface. In comparison, the sensor chip itself is negligible fast. If outside methane concentration changes, a mass transport occurs and concentrations have to re-balance. This equalisation process takes several minutes in this two-phases system due to phase transitions between the liquid (seawater-dissolved methane outside) to the gaseous phase (sensor’s interior). Until steady state is reached the sensor signal does not reflect the actual outside concentration but rather the sensor’s interior.

The sensor can be considered as a system, whose known input signal is the seawater methane concentration and the observable output consists in a voltage. The correlation of input and output signals is given by largely unknown subsystem properties. Theoretically, the signal modification is subject to different transfer functions schematically shown in the following figure.

![Figure 6. Flow scheme of transfer processes from a chemical input value (methane concentration) to an electrical output (voltage).](image)

A first step towards a fast methane measurement system is the development of a model accounting for all sensor subsystems. A series of experiments is needed to identify the model parameters and to perform model validation.

Subsequently, the model information is used to design an optimal observation system that allows the fast estimation of the true methane concentration from all available information. The model can be extended to incorporate temperature and humidity data (sensor fusion).

The last step consists of the implementation of an algorithm or a method, that is able to predict the methane concentration in sea water in real-time by digital signal processing.
Development of a flow-through chamber – sensor specification (AWI)

A flow-through chamber, in combination with a pressure resistant pump, shall maintain a constant approach flow instead of changing flux conditions at the sensor membrane. To minimise constructive efforts, a depth (pressure) rated SeaBird™ CTD pump was integrated. Design and CAD construction based on the combination of METS and deep-sea CTD pump is shown in Figure 7.

![Figure 7. Combination of methane sensor and deep-sea CTD pump](image)

WP3.3 In situ sensors - Optimisation of a hot film sensor

Author: A. Schultz (CARDIFF)
Contributor: P.M. Sarradin (Ifremer)

Cardiff University is responsible for the optimisation of a hot film flow sensor that had been developed in our lab. The project is on-track to meet the project requirements. This has been made possible by our ability to co-develop and refine this sensor using non-EXOCET/D resources, according to the specific text in the EXOCET/D project description (Annex I), tasks, requirements and objectives of part of WP3.3 – hot film flow sensor are summarised below.

**Modification of thermal flow/temperature sensor to reduce overall size and to reduce thermal response time**

We have recently completed the re-design of the small printed circuit board that is used as the foundation of the thin film sensor assembly. A set of sensors is being built up on these boards with an effort being made to reduce the overall thermal mass, and thereby to reduce the characteristic response time of the system. This work is presently on-going.

**High frequency measurement at 1 Hz or faster by use of new analogue-to-digital converter system**

We have gone through two complete iterations of re-design of the printed circuit board that contains the data logger/control system/analogue conditioning circuitry for the sensor. We now use a universal controller board design that is shared between all instruments designed in our laboratories. Each controller board contains an 8-channel 24 bit analogue-to-digital converter capable of operating at up to 10 Hz sampling rate; an integral programmable gain stage providing gains of up to 128; motor actuators; rotary encoder decoders; real-time clock; SD memory card; and a series of digital interfaces (described below). Depending on firmware configuration, the
board may be used to control the thin film flow sensor; or to control isosampler valves or pumps; or virtually any device. We have therefore met and exceeded the requirements for Step 2.

Software developed to enable system to work either connected to ROV or manned submersible, or to work autonomously recording data on flash memory devices.

We record data internally on SD memory cards, and can telemeter data externally using a variety of interfaces. At the moment SD cards come in capacities of up to 1-gigabyte. We are presently implementing a PC/FAT file structure for these cards, so they can be removed and read on any PC/Mac. The network interfaces enabled on our controller board include SPI-bus (for low-level inter-device connection at the circuit board level); CANBus for connection between boards or with the outside world; and a legacy Serial RS232 connection. Outside of EXOCET/D (we are not funded to do this within EXOCET/D), we also hope to implement an Ethernet daughterboard that can live inside the same pressure housing as the main controller board – and we are presently implementing TCP/IP protocols on the controller board. This would mean that the sensor could be accessed through e.g. a web server, ftp etc over standard Ethernet interfaces. We have met and are likely to exceed the requirements for Step 3.

Software developed to permit access to raw data and possibility to make and use post-laboratory recalibration constants.

This is on-going. We will meet the requirements for Step 4 within the specified time period.

Reduction in power budget by management of constant or pulsed sensor heating.

We have completely redesigned the thin film flow sensor current source and the measurement approach. We now use a common current source across both thin film devices. This reduces the power requirements. It also reduces the possibility for long-term sensor drift. Previously, by having different current sources for each RTD, it was possible for small drifts in each source over time to lead to differential excitation of each sensor, which would appear as a difficult-to-correct drift. This has now been improved. We also now enable pulsed sensor heating. We have met the requirements for Step 5.

Sensor calibration set from 2 to 80°C at 1 bar hydrostatic pressure

Calibration has been a major theme of this year’s engineering developments. We have recalibrated several generations of our previous sensors, and now have a much better model of response of these sensors both to flow rate, and to changes in environmental temperatures. These sensors are sensitive linearly to temperature, and logarithmically to flow rate (most sensitive to low flow rates, and less so to high flow rates).

We have identified several sources of potential thermal sensitivity on the flow channel, and also several sources of long-term drift. In previous versions of the sensor, changes in water temperature in the region of the connector at the pressure case, through the undersea cable, and up to the sensor itself was possible and could introduce offsets in the signal. This was due to a set of bi-metallic junctions along this pathway, setting up a thermocouple effect; and also to changes in the impedance of the cable as a function of temperature. There were also the aforementioned drift terms due to use of different current sources for different RTDs. We have now implemented a full 4-wire resistance measurement approach, which eliminates all of the connector and cable effects. The common current source also improves the ability to calibrate and eliminates drift.

In addition to enabling pulsed sensor heating, we have also enabled pulsed sensor excitation - that is in addition to being able to turn the sensor heater on and off, we can also turn on and off the small current source that is used to determine the resistance of each thin film device. In this way we can make a quasi-AC measurement that should eliminate signal offsets due to self-heating.

Finally, we can now measure the temperature and also monitor the electrical current flowing through the heating element. It turns out that changes in water temperature lead to sufficient changes in the impedance of the heating element that (since we used a constant voltage source to excite the heating element) lead to changes in heat output (power) from that heating element -
which amplified the temperature sensitivity of the flow channels. This has now been addressed. So there have been major efforts to identify each source of temperature dependence and long-term drift, and to eliminate them or to make them measurable so they may be removed.

The only difficulty remaining is in setting up a calibration facility that is sufficiently controllable, and stable enough, to meet the sensitivity and accuracy of the sensor itself. This has been a long-standing problem since there are no commercial solutions for reproducing seafloor conditions suitable for the sensitivity of our sensor, and since we relocated our lab it was not practical to relocate the large (and insufficiently controllable) calibrator we had built there.

An outside engineering company designed us such a calibrator that is controllable in 1 mm/s increments for flow speeds of 1 mm/s to 1 m/s, and controllable in 1 °C increments for temperatures of 2.5°C to 90°C, all at 1 bar. The cost of producing this and installing in a newly renovated lab designed to accommodate this 8-9 m long calibration system, is approx. 70,000 € which is not available in the EXOCET/D budget. We have proposed that NASA fund such a system as part of a larger project, and are waiting to hear the outcome of our proposal. If funded we will meet the requirements of Step 6. If not, we will need to consider other options to meet these requirements.

**Static pressure certification at 600 bars hydrostatic pressure**

We have installed a controlled high pressure calibration tank in our lab that can reach 600 bars. We will meet the requirements of Step 7.

**Demonstration on seep or hydrothermal vent on cruises of opportunity**

We are willing to take part in cruises to demonstrate the capabilities of the sensor. We made several cruise proposals (Hydrate Ridge in the NE Pacific Cascadia Accretionary Prism, Endeavour hydrothermal field Juan de Fuca Ridge, Bransfield Straights) and we are waiting to hear about the outcome of those proposals.

**Feasibility study (prototype) on 2 (3)D velocity measurements**

We have a notional design for a 2D version of the sensor and plan to build one up and test it during the coming year.

**Feasibility study on adding acoustic Doppler current sensing to augment thermal flow/temperature sensor package**

We will carry out a short feasibility study for supplementing the thin film sensor with a Doppler.