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Development and Operation Of an AUV-Based Water Sample Collector

New Device Integrated With Bluefin-21 AUV Collects Water Samples From Below the Arctic Ice

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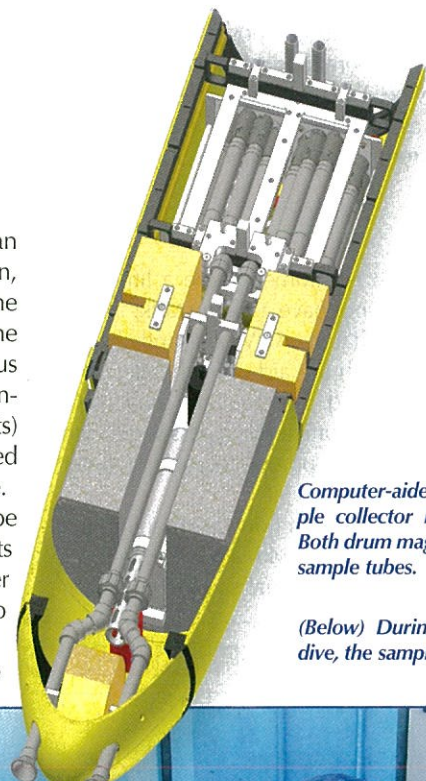
Within the framework of the second leg of the German research icebreaker *Polarstern*'s 25th Arctic expedition, ARK XXV/2, which took place from June 30 to July 29 in the Fram Strait, the Alfred Wegener Institute for Polar and Marine Research (AWI) accomplished its first under-ice autonomous underwater vehicle (AUV) mission. Along with various sensors, the Bluefin Robotics Corp. (Cambridge, Massachusetts) Bluefin-21 AUV's payload included a newly developed water-sample collector that gathered samples under the ice.

The AWI has owned the Bluefin AUV since 2003. This type of vehicle is especially useful to the institute because of its ability to operate without a physical connection to a mother ship, enabling it to dive in ice-covered areas, opening up completely new possibilities for polar research.

With this in mind, in spring 2008, the AWI made the decision to develop a water-sample collector for the Bluefin-21 vehicle. Actual work on the system began in September 2008.



Computer-aided design model of the sample collector inside the Bluefin-21 AUV. Both drum magazines are fully loaded with sample tubes.

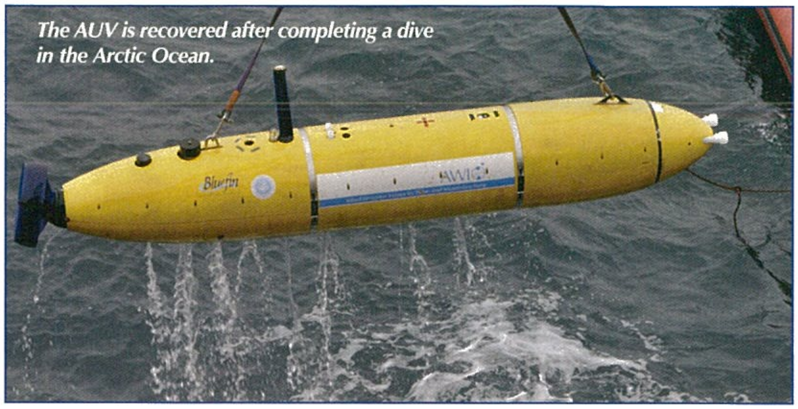
(Below) During preparation for the next dive, the sample tubes are inserted.

Basic Conditions

From the beginning of the design process, scientists of different disciplines were involved in the sampler's development. The goal was to build a sample collector that meets the requirements of various research fields and is therefore versatile.

In order to gather a large number of samples, the volume has to be as small as possible, but big enough to meet the demands of several analytical methods. As it turned out, the best possible compromise was a sample volume of 200 to 250 milliliters.

Due to purity criteria, the materials choice for the sample collector was limited. Only advanced materials, like the plastics polytetrafluoroethylene and polyvinylidene fluoride (PVDF) or 316Ti stainless steel, were allowed to be used for parts that come into contact with the samples. As the hull of the AUV consists of acrylonitrile butadiene styrene, water that might have come into contact with the hull must also be classified as "probably contaminated." Consequently, inlet openings to the sample collector needed to be positioned in front of the AUV.


The AUV is recovered after completing a dive in the Arctic Ocean.

In addition to the scientific requirements, the operating conditions also needed to be taken into account. The amount of available space and the carrying capacity of an AUV is limited. As a consequence, the design of the sample collector had to be compact and lightweight. The interior of the Bluefin-21 vehicle, including the payload section, is flooded completely. Consequently, during a dive, the sample collector is exposed to harsh environmental conditions (e.g., pressure). Operations in polar areas can also entail very low temperatures. Although the temperature of the water seldom falls below -1.8° C, longer downtimes on deck with significantly lower air temperatures might cause a much stronger cooling of the device. The use of cold-resistant components was mandatory, as was vigilance in the design to include tolerances and free spaces to allow for thermal expansion.

Functional Principle

For safety reasons, the AUV is trimmed to be a little less dense than water. Since it does not have a diving tank, it only dives dynamically. That means that the AUV constantly has to push itself below the surface with the aid of its thruster and, as a consequence, moves forward. This forward movement causes a dynamic pressure that is sufficient to press water into the interior of the vehicle, making pumps to suck in water unnecessary.

Thus, the intention was to integrate a flow channel into the AUV that is interrupted by a magazine with a number of sample containers. This magazine is the actual sample collector. Similar to the functional principle of a revolver, the sample containers (sample tubes) are arranged in a rotating drum magazine, and one particular tube is positioned in front of the feed line (like the barrel of a revolver). In a continuous process driven by the motion of the AUV, water enters the feed line, flows through the sample tube and leaves the AUV through a drainage pipe.

If the drum magazine is turned one tube further, this has a double effect: The rotation both positions a new tube in front of the feed line and triggers a closure mechanism in the tube that had been in front of the feed line, closing both ends of the tube. Through this process, a section of the water flow is isolated as a sample.

The sample collector contains a total number of 22 sample tubes, each with a volume of 220 milliliters. These tubes are mounted in two separate magazines. Each of the magazines has its own feed line, drainage pipe and drive motor. The motor is attached to the sample collectors' front and back side, respectively. The integration of two independent magazines minimizes the risk of a total failure of the sample collector, and the space in the payload section is used more efficiently than with one magazine.

The inlet openings of the two feed lines are situated in front of the nose cone of the AUV and are visible in the form of two funnels. The feed lines then lead through the battery section of the vehicle before they are finally attached to the sample collector. The feed lines, including the funnels, consist entirely of PVDF. The openings of the drainage pipes are visible on top of the payload section directly in front of the global positioning system antenna.

Sample Tubes

The functional principle of the sample tubes is similar to that of Niskin bottles. The interior of both ends of the tube are shaped conically so that female tapers are formed. These female tapers serve as counterparts for two cones (locking cones) that are interconnected by a tension spring. Prior to a dive, the two locking cones are lifted from their tapers and fixed at special suspension points inside the tube. When the drum magazine rotates, small levers, which are a part of the closure mechanism, release the locking cones from their suspension points. The force of the tension spring pulls the cones into the tapers and thus closes both ends of the tube.

Another central component of every sample tube is the moveable endcap. This endcap is adjustable to a range of 10 millimeters, and therefore the overall length of the tube is flexible. A pressure spring below the cap produces a counteracting force if the tube and cap are pushed together. When the sample tubes are mounted in the drum magazine, they move in between two Teflon®-coated slide plates. The distance between these two plates is chosen so that the tubes cannot extend to their maximum length. Hence, the pressure spring is constantly compressed and the ends of the tubes are steadily pressed on the slide plates. When positioned in front of the feed line, this contact pressure seals the transition point between tube and feed line—an important precondition to ensure that only "clean" water can enter the sample tube.

Operation on the ARK XXV/2

During expedition ARK XXV/2, 12 dives were performed between July 2 and July 21. Unfortunately, frequently occurring fog strongly handicapped the work, so eventually only one (and the AWI's first) under-ice mission could be accomplished. The scientific goal of this particular mission was to measure biological parameters that have an influence on phytoplankton. Therefore, in addition to the sample collector, a sensor for photosynthetically active radiation, a fluorescence sensor and a conductivity, temperature and depth probe were sent along with the AUV.

The under-ice mission was executed in the western Fram Strait (78 degrees 49 minutes north latitude and three degrees 49 minutes west longitude) on July 21 and led the AUV about two kilometers under the ice. The vehicle was deployed 800 meters in front of the ice edge and transited to the ice at a depth of 20 meters. At 300 meters in front of the ice edge, it descended to its actual mission depth, which was 27 meters, the depth at which the vehicle was expected to hit the fluorescence maximum. This was the most interesting water layer for the mission.

The process of taking samples was launched by a pressure sensor that identified the intended depth. Water samples were taken in discrete time intervals of 90 seconds each. After reaching the turning point, the AUV returned to a preprogrammed position and was picked up by *Polarstern*.

After the vehicle had been recovered, the water samples were immediately given to scientists to be prepared for conservation. The tubes were taken out of the sample collector, stored in special transport containers and brought into the laboratory within a few minutes. Because of the much stronger levels of light at the surface, the samples were darkened with an opaque film during tube-dismounting. According to a pre-developed procedure, the samples were then divided into several fractions and preserved in *Polarstern*'s cold stores.

Conclusions and Future Prospects

Over the course of the ARK XXV/2 expedition, the functional principle of the sample collector, as well as its design, performed well. While sample analysis is not yet complete, there are no indications of any malfunctions or major construction faults that might endanger the purity of the samples. The handling of the sample tubes and working in the laboratory proved to be simple and safe.

AUV operations during ARK XXV/2 demonstrated the great potential of the combination of an AUV and a sample collector, and biological research could potentially reap a large benefit from this partnership in future missions. For the foreseeable future, there is still a large number of analysis methods that cannot be replaced by sensors and *in-situ* measurements. Therefore, gathering sample material is a fundamental part of scientific work.

Without an AUV, a team of scientists must go onto the ice and drill holes to gain access to the water below. For Arctic sea ice, this might be difficult and time-consuming, yet feasible. In the case of shelf ice, however, with several hundred meters' thickness, this method reaches its limits. Although it already has been done, these drilling sites remain isolated. For large-scale investigations, AUV-based systems are the only access to the unknown world that lies under the ice.

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