Pressure-Compensated Lead-Acid Batteries for Submerged Applications

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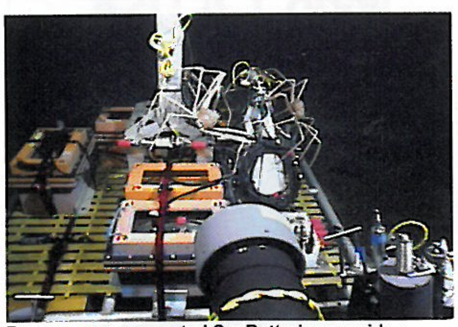
The idea is Power under Pressure. If storage batteries can be made to work across the extremes of pressure, the need for heavy, bulky, expensive pressure housings is eliminated, and power can be delivered within smaller weight and space constraints, with arguable improvements in system safety.

Pressure compensation means the electrolyte is at ambient sea water pressure. This is achieved by filling the internal air space of a battery above the plates and electrolyte with an inert fluid, often white mineral oil, with enough excess volume to compensate for temperature and pressure effects.

In 2010, ABS Type Approval will be necessary for systems utilizing pressure-compensated batteries conforming to ABS Rules for Building and Classing Underwater Vehicles, Systems, and Hyperbaric Facilities.

A BRIEF HISTORY

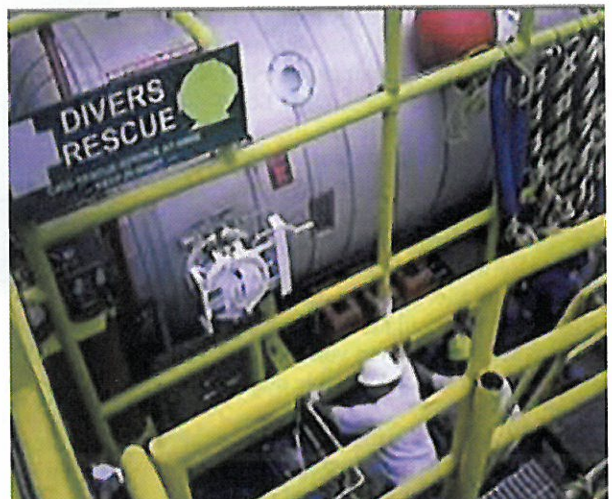
Batteries generate electrical power by making use of electro-potential differences of dissimilar materials brought together in an ion-rich media called an electrolyte, and connected by a separate electrical path, called a circuit. Batteries are divided into two main groups: non-rechargeable or primary batteries, and rechargeable or secondary batteries.



Pressure-compensated SeaBatteries provide a useful holdfast for large spider crabs on this WHOI seafloor package.

Invented in 1859, lead-acids were once only available as "wet-cells," with the undesirable consequence of spilling battery acid if tipped past their "spill angle". They also require routine maintenance to replace the water in every cell which is lost to evaporation, or, of greater worry, from electrolysis which produces a combustible hydrogen-oxygen mixture.

They got progressively better over the next 90 years, the problems mitigated, and the advantages of lead-acid batteries were finally adapted to deep submergence vehicles and platforms, both manned and unmanned. Pressure compensated lead-acid batteries were used for critical functions of main propulsion, guidance, and life support since at least 1948 with Swiss Professor August Piccard's FNRS-2 bathyscaphe.



Multiple SeaBatteries provide emergency life support for saturation divers during hyperbaric evacuation aboard Cal Dive International's DSV *Mystic Viking*, October 2008.

From the mid-1960's until the late 1970's, Scripps Institution of Oceanography/ UCSD's researcher Dr. Frank Snodgrass fabricated pressure compensated wet cell lead-acid batteries that served the secondary purpose of drop weights during the "Mid-Ocean Dynamics Experiment," (MODE). These instruments operated continuously and unattended for up to a year at a time prior to acoustic release and instrument recovery.

Gel cells are a substantial improvement over wet-cells. The electrolyte is mixed with a very fine silicon dioxide powder to create a gel-like paste which won't spill in any orientation. Gel cells are leak proof, and produce minimal off-gassing that can build-up excess pressure and be potentially explosive. But the best was yet to come.

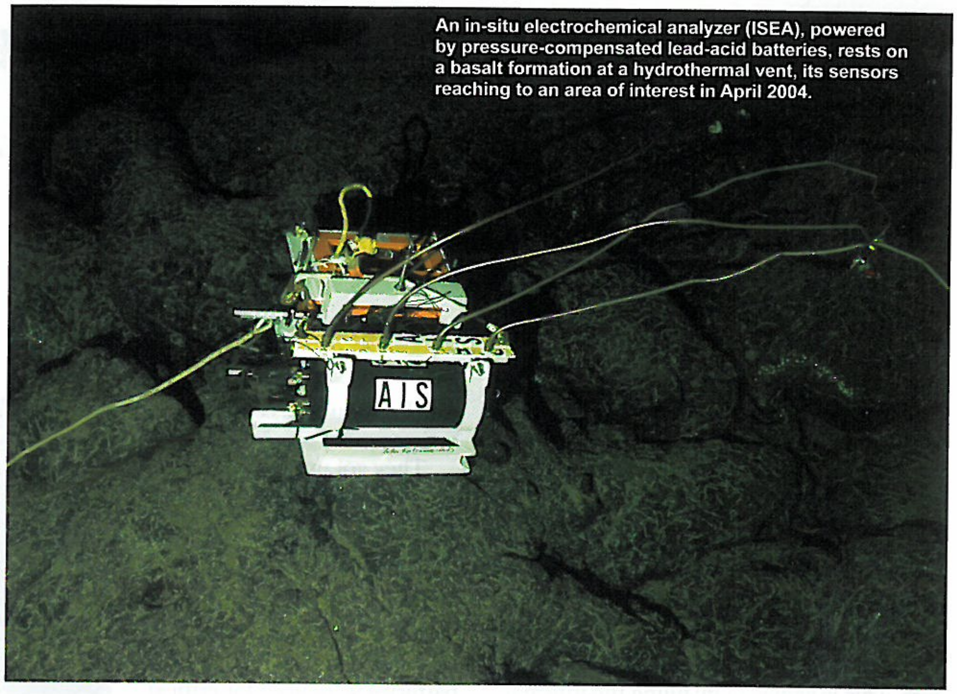
TODAY'S LEAD-ACID BATTERIES

Today, the Absorbant Glass Mat (AGM) lead-acid reigns as the most advanced sealed lead-acid battery available. The AGM battery has all the advantages and more of gel cells, with none of the downsides. AGMs use electrolyte saturated absorbent boron silicate glass mats between the plates. The plates and glass mats are sandwiched tightly together within a rigid frame. As a result, they are very shock and vibration resistant, and can be operated even if inverted. AGMs are more readily available, less costly and more easily shipped than exotic batteries such as Li-Ion and Silver-Zinc. The additional weight is often used to counter-ballast the air-filled envelope housing instruments or personnel. Some AGM batteries are designated as "high rate discharge", and can deliver short bursts of higher current due to higher electrolyte concentration, wider and taller plates, and textured plate design that provides greater surface area.

Additional features of today's AGM lead-acid batteries still make them the best choice for many applications. While lower temperatures in the deep sea lowers the capacity of all batteries, the associated higher pressure increases the capacity in lead-acid batteries, tending to balance the two effects. But lower temperatures also increase the charge retention ability of lead-acids, an important feature for long term deployments.

Absorbent Glass Mat (AGM) batteries inherently produce very minimal gas in normal operation, allowing them to be designated "maintenance free." AGM batteries are "recombinant", meaning the oxygen and hydrogen created while charging recombine back into water inside the battery. This is due in part to the use of low or zero antimony lead alloy grid. The recombinant affect is typically better than 99% efficient, so almost no water is lost, and almost no gas is generated. Gas generation is typical with battery overcharging, not discharge, and more so with wet cell batteries than AGM cells. This has been confirmed in testing at DeepSea Power & Light (DSPL).

Any gas volume that may be generated can be captured by a flexible diaphragm, and vented manually or by use of a pop-off valve. For added safety, DSPL recommends recharging their AGM SeaBattery on deck, where a technician can oversee the process, and vent any gas generated.



An in-situ electrochemical analyzer (ISEA), powered by pressure-compensated lead-acid batteries, rests on a basalt formation at a hydrothermal vent, its sensors reaching to an area of interest in April 2004.

COMPONENTS

Pressure compensated batteries often have the following components or features:

A. The specially modified AGM lead-acid batteries and wiring, including a feedthrough to a wiring harness.

B. The housing, usually a single piece, impact resistant plastic box with a mating lid and seal. DSPL housings are a heavy wall, rotationally molded, Liner Low Density Polyethylene (LLDPE).

C. The pressure compensating device that produces a slightly positive pressure over external ambient pressure. Positive internal pressure allows for inspection for leaks prior to deployment. The fluid compression and thermal expansion characteristics are both calculated and measured to ensure there is sufficient volume used. A compensator may be a flexible diaphragm, a piston, or a bellows.

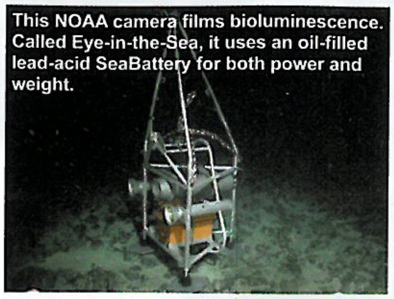
D. The compensating oil is inert to the electrolyte and battery chemistries, and possesses low vapor pressure at room temperature, with a density less than the battery electrolyte. The oil is non-conductive, has low flammability, is non-hazardous to humans on contact and to the environment if spilled, and is safe for aircraft transportation. Clear mineral oil, such as Drakeol 35, is often chosen.

E. The fill port is sealed by a cap seal, and is alternately used to vent excess gas. Provision could be made for automatic venting of excess gas, like a pop-off valve, but this has to be done with some forethought to avoid subtle problems such as contamination and leakage.

G. Underwater bulkhead electrical penetrator or rubber molded cable feedthrough rated for max transmitted power.

H. A set of handles will make lifting easier for the deck crew.

I. Battery charging should be possible with the battery installed in the underwater system as long as the operator is able to inspect for outgassing and open the vent if needed. The charger must be designed to limit charge rate and total charge to minimize gas generation.


This NOAA camera films bioluminescence. Called Eye-in-the-Sea, it uses an oil-filled lead-acid SeaBattery for both power and weight.

L. Shipment: Ground transportation is the generally preferred method of shipment as it is the cheapest way to move the weight of the battery, though it does take longer. Pressure compensated AGM lead-acid batteries have the advantage of using components that in aggregate may be labeled non-hazardous for cargo-only air shipment, if there is an urgent need for delivery. The shipping box must conform to all applicable DOT/IATA construction requirements.

In addition to a type approved battery, ABS system requirements include the use of overload and short circuit protection, per section 11.13, breakers or external fuses, per section 15.5, switch and proper wire size and construction.

In qualifying the battery type and manufacturer, DSPL found AGM batteries are run through rigorous manufacturer's performance tests, all useful characteristics in the offshore field.

ABS TYPE APPROVAL

ABS Rules for Building and Classing Underwater Vehicles, Systems, and Hyperbaric Facilities (2002), defines general PBOF battery specifications in section 11.7: Pressure Compensation. DSPL's SeaBattery is now Type Approved by the ABS for use at sea on projects requiring ABS certification. The procedure for a product becoming ABS Type Approved involves 3 steps.

1. An Engineer's evaluation of a design to determine conformance with specifications. The manufacturer submits sufficient information to allow ABS to determine if the product meets specification. This results in a Product Design Assessment Certificate.
2. An ABS Surveyor witnesses the manufacture and testing of a sample of the product to determine compliance with the specification.
3. An ABS Surveyor's evaluation of the manufacturing arrangements to confirm that the product can be consistently produced in accordance with the specification. This results in the issue of a Manufacturing Assessment Certificate (MAC).

An Annual Plant Survey is required for maintenance of ABS Type Approval.

CONCLUSION

Batteries are useful underwater tools to produce electrical energy. Dissimilar metal plates suspended in an electrolyte produce current when they are connected through an electrical circuit. Low temperature, high pressure, and long duration deep sea deployments can be accommodated.

Rechargeable lead-acid storage batteries have been used in many marine applications, such as military submarines, for more than a century. Problems with outgassing of hydrogen, oxygen, and acid fumes, plus cell leakage into the interior of a submarine hull, put early adopters of these electrical storage devices at risk.

Since then, substantial work has been done by generations of engineers to mitigate these problems. Improvements have been made in all regards, and the design goal of producing a rugged, easy to use undersea battery capable of producing high currents on demand, without the added cost and weight of a bulky pressure case is now a commercially available component.

In July 2007, multiple deployments of DSPL's SeaBattery to 10,800m in the Tonga Trench as part of the University of Aberdeen's OceanLab Hadal-Lander confirms the ongoing usefulness of this approach. In the OceanLab application, the batteries are recovered by the use of additional buoyancy, and only a benign iron weight is left behind. **UW**

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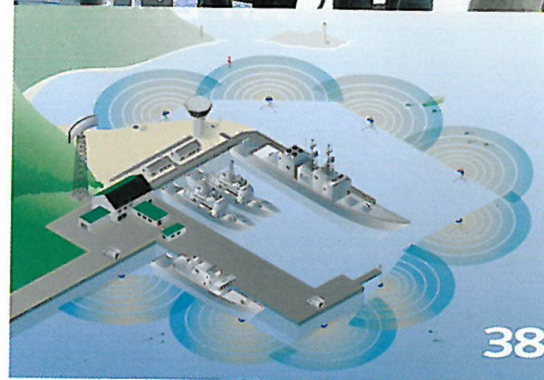

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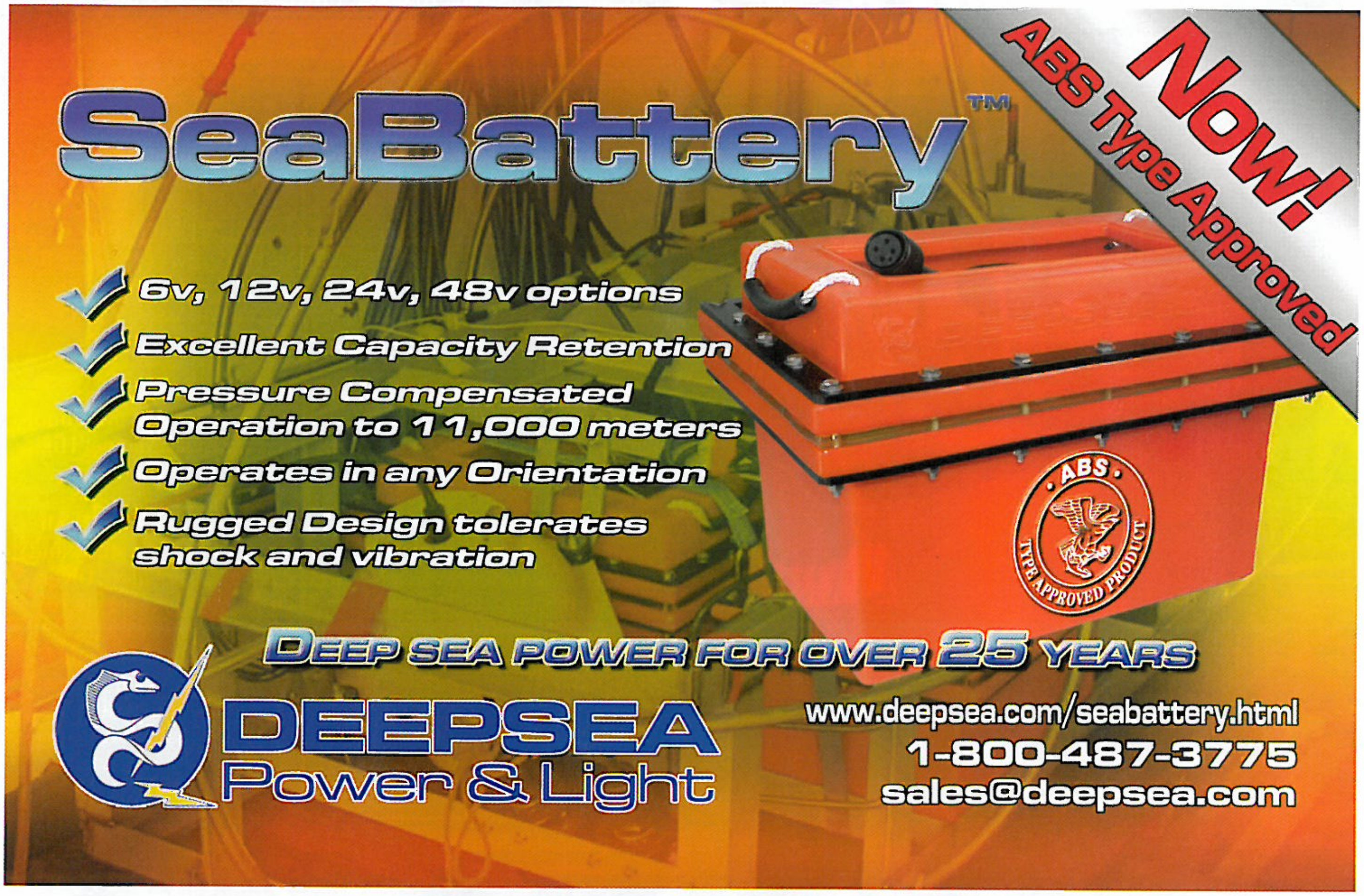

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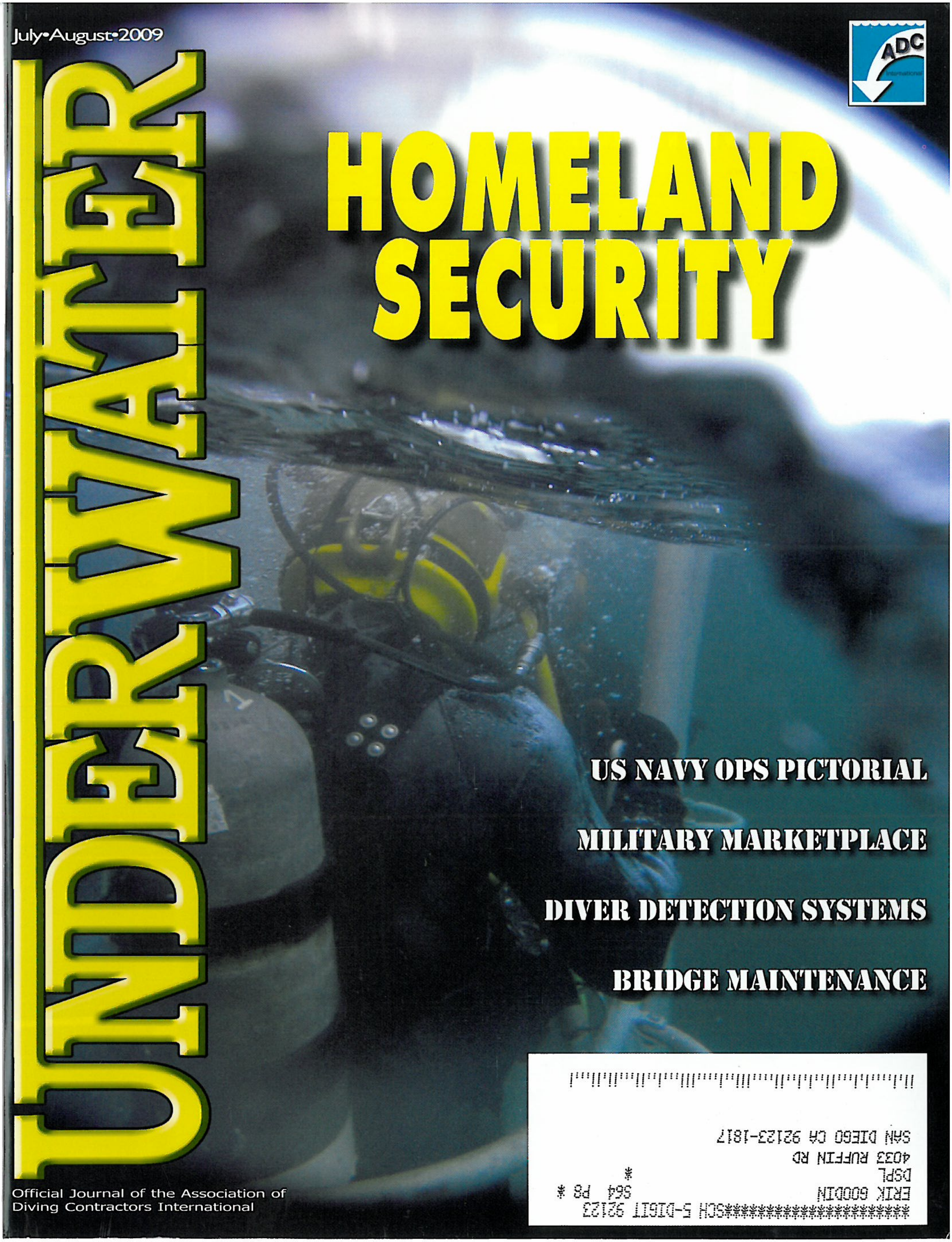

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