RESEARCH ON SATURATION DIVING IN POLAND AND ITS IMPLEMENTATION. PART I B. GENERAL CHARACTERISTICS OF SATURATION DIVING RESEARCH IN OUR POLAND. PIONEER TIMES; 1967- 1985

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ABSTRACT

The article is the first in a series of articles on the research and implementation of saturation diving technology in our country which presents the specific Polish conditions and achievements against the background of economic and historical circumstances. In view of the fact that research and implementation has a history of more than half a century, selected key figures of this period are recalled, some of whom have disappeared in the fogs of history. In the specialized literature of the world, the Polish underwater habitats of Meduza are among top 6 countries that researched and implemented, this high technology of saturation diving. Regarded as the inspirer , pioneer and creator of the first saturation diving, he designed and developed the technique and decompression with the cooperation of a team of enthusiasts from clubs and professional divers, as well as engineering staff from the Tri-City enterprises. In the first part of the article the author characterizes the saturation dives in comparison with short dives with particular emphasis on decompression, which is the key to safe diving. The article also takes into account the technical conditions for the implementation of the first saturation dives. The author discusses the general methodology of validation and verification of the assumed decompression, referring to the Polish conditions. He describes how the medical, technical, and organizational problems of implementation of saturation diving were solved in the pioneering period against the background of world achievements. Furthermore, the author describes Polish habitat constructions of Meduza and Geonur types and their application to underwater work on the Polish shelf and coastal areas. Despite the great progress in the field of medicine and technology, as well as organization, the problems of saturation diving, despite the passage of time, remain relevant , as these are the most difficult dives from the point of view of organization, underwater physiology and safety technology.
Keywords: pioneering implementation of saturation diving, medical and technical problems of diver decompression, research validation of decompression tables, saturation diving, saturation diving parameters, underwater work, diving system, saturation diving, decompression of divers underwater habitat, decompression tables.

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INTRODUCTION

POLAND AS ONE OF GLOBAL PIONEERS OF SATURATION DIVING

It is commonly assumed that commercial saturation diving in countries operating offshore (USA, UK and France) emerged as a fully-fledged activity between 1960 and 1980. Poland made its way into the pages of the world history as one of the first countries using this diving technique. According to the European sources, Western and Eastern alike, diving in MEDUZA (Meduza) chamber was one of the first 20 experimental dives in the world. In records from the 1960s, Poland ranked 16th on the lists of experimental diving. Saturation diving using MEDUZA 1 began in parallel with research conducted elsewhere [1,2]. In most countries, research into saturation diving was carried out by specially established research centres working for the defence sector and the offshore industry. Yet, at that time there were no research centres in Poland that would be ready to undertake such studies, even though the maritime sector was interested in exploration and extraction of raw materials from the seabed, and in carrying out maritime salvage operations not only in Poland. The first experiments in this field in our country were conducted by a group of enthusiasts from the GKP "POSEJDON" diving club supported by the engineering staff from underwater service companies such as the PRCIP (Przedsiębiorstwo Robót Czerpalnych i Podwodnych) Ridging and Underwater Works Company Ltd., and medical doctors from the Polish Maritime Salvage organisation.

In the 1970s and 1980s research tended to focus on the assessment of mineral resources and the development of methods for extracting them from the coastal zone and the sea shelf. The Polish Society of Friends of Earth Sciences (Polish abbr. PTPNoZ) took up the subject of bathyscaphe-nautical research by setting up a team at the Pomeranian Branch of the Society for this purpose. The team designed and built two bathyscaphes Geonur 1 and Geonur 2. These structures helped in resolving some major physiological and technical problems occurring during deep-sea and seabed exploration.

Undoubtedly, the first experiments in saturation diving could take place because there was a group of enthusiasts led by Antoni Dębski, who many consider the father of Polish bathyscaphe nautical studies. This is all the more remarkable given that he was only a technician and an autodidact. His knowledge and skills were the result of his incredible passion, having a good nose for technical engineering and his commitment.

The history of Polish submersible watercrafts begins in 1967 when the first almost handmade Polish diving chamber was constructed."[3] Most of the submarine solutions and equipment used by the Polish maritime industry in the 1970s and 1980s were designed and made by the Gdynia Shipyard. To quote the main designer of the vessel: "it was like punching a hole with your head in the wall of habits." The reasoning was quite simple: if a diver is to stay underwater for longer periods of time, it is necessary to ensure them living conditions a little better than a well-insulated wetsuit. This is where the concept of Meduza 1 chamber came from. The project was a combination of a patriotic act, as "Poles are not anserine", and also a desire for adventure and venturing into the unknown. The history of Polish bathyscaphe-assisted diving began in 1967, when our first almost handmade underwater diving chamber was built [3].

Poles, similarly to the French, were doing their best to prove that their creativity and inventiveness would solve any problem related to diving. The difference was that in France, at a certain stage, the project received the attention and support of the government and rich French companies. All innovative solutions and ideas that required testing and further research were tested by enthusiasts and people committed to the project on themselves. This was the case with investigating the effects on the diver's body of staying at shallow depths for long periods of time and breathing in compressed air. At that time, no one in Poland had ever tested this before, and the world's experiments in this field were also in their early stages. Many 'wise guys' asserted that A. Dębski was thus putting in danger not only his own life, but that of his colleagues as well. Nevertheless, his amazing ability to persuade and bring together enthusiasts, adventurers and people from the maritime industry enabled the carrying out of projects that led to the extension of divers' working time, so necessary in the maritime sector. Despite the disapproval of many researchers and experts dealing with diving, specialised decompression tables were put together, allowing for the safe use of the new equipment. The first decompression tables for Meduza project were developed by A. Dębski and his team based on scarce data from around the world. They availed themselves of data from the US Navy tables providing times for divers remaining 6 hours under pressure, random data from France and even a methodology for calculating the tables from the Czech company Aqua Cetrum. Geonur 1 programmes used tables developed for Meduza 2 and the Central Institute for Labour Protection [4,5].

MEDUZA 1

It all started with reading press reports informing that French free diving pioneers, Jacques Cousteau and friends, succumbing to the charm of the underwater world, began to dream of a *'homo-aquaticus'*, i.e. underwater human life. This led to the creation of their 'underwater habitat', a kind of a diving bell called 'Diogenes'. Several divers spent several days in it at 16 metres. Antoni Dębski, a mechanical technician, graduate of the Gdynia Sea Fisheries School, employee of the Gdynia Shipyard, and a member of the Gdańsk Divers' Club 'Poseidon' got extremely interested in what he had read about the French experiment and he started thinking about building a miniature 'Diogenes.' A. Dębski managed to pass on this idea to a chemical engineer, Alexander Lassaud, M.Sc.

The enthusiasts were closely watched by a diving instructor, a hydrotechnical engineer, M.Sc., employed at the Ridging and Underwater Works Company Ltd. [Polish abbr. PRCiP]. He decided that the idea of a Meduza chamber could be useful for the PRCiP's underwater works carried out at considerable depths in mountain hydroelectric plants. For the Meduza 1 experiment, its originators recruited a group of people, who were not scientists but very much wanted to help with the project. Unfortunately, they also lacked the necessary background, training, and technical support. The reason was simple. Those who had the required resources at the time, i.e. the knowledge, access to laboratories, technical means, equipment, etc., had little leeway as they had to observe stringent regulations and organisational ramifications. Moreover, they were rather conservative and did not want to get involved in an 'affair'. In contrast, a group of relatively young enthusiasts wanted to act and were ready to take risk.

The PRCiP agreed to take over the Meduza project and commissioned the Gdynia Shipyard to construct the chamber. Meduza was built from waste materials by divers from the Self-Defence Section after their regular working hours. It was designed by a team comprising: a technician Antoni Dębski, M.Sc., Eng. Jerzy Kuliński, and M.Sc., Eng. Aleksander Lassaud. Thus, one can say that a diving chamber using pressurised air as a breathing medium was almost entirely homemade [6]. When working on the Meduza project, the idea of using a ship as a diving support vessel or lifting equipment had to be completely abandoned, meaning larger dimensions of the chamber were not a viable option. Meduza was a "demountable chamber" that could be transported by truck and manually reassembled directly on the lake [7]. Under such circumstances, the most important was its ability to submerge in water independently and to move at different depths set by the crew. This problem was solved with a bottom ballast connected by a steel cable to a winch inside the chamber. This system allowed any decompression to be carried out at the end of the submersion period.

These are some technical data of the chamber:

- Water displacement volume 3750 dcm3 for the weight 2950 kG, bottom ballast weight 1300 kG,
- Dimensions: length - 220 cm, height - 210 cm,
- Compressed air supply - 24 cylinders with water capacity of 40 l and 150 atm, including 6 cylinders with 37% oxygen decompression mixture and 2 cylinders with oxygen,
- Equipment that maintains normal atmospheric parameters: 200W heater, CO absorber with a blower, gas analysers,
- Equipment: Wired telephone, rest berths, chamber winch with manual drive adjustable by divers. 24V shore power from a 400W rectifier [6].

Medusa's design provided the first Polish aquanauts with conditions that were, to put it mildly, rather spartan. The so-called habitability of the chamber corresponded to that of a medium-sized diving bell. According to the opponents of this experiment, those who built the chamber failed to meet the minimum conditions for diver comfort. With the benefit of hindsight, one needs to admit that the conditions for the divers were indeed incompatible with the then binding standards. Yet, the participants of the experiment and media representatives who supported their 'crazy expedition' believed in its success.

The 'Meduza' chamber dived in water for the first time on Lake Kłodno on 14 July 1967 at 13:00 hrs and reached a depth of 17 m at 18:00 hrs. It remained at this depth until 04:00 hrs to reach 24 m on the next day at 05:00 hrs. The depth of the lake is 38 m. Atthea depth of 24 m, the chamber with the crew (Antoni Dębski and Aleksander Lassaud) stayed until 20:00 hrs on 17 July 1967 when a stepwise decompression began. The chamber emerged and the crew left the chamber at 13:00 hrs on 18 July 1967. [7, 8]. During their stay inside the chamber, where the humidity reached almost 100% the aquanauts felt cold. They were supplied with meals and all necessary materials by assisting divers [7]. Notably, when they were at the depth of 24 m, the crew reduced the percentage oxygen content to 10% and increased it to 14% before decompression. In the final phase of decompression from 9 m depth, nitrox with 37% oxygen was used.

Decompression-related data and the stay at a depth of 24 m for 79 hours plus a 17-hour decompression are confirmed by the documents and log data from this experiment [7,8,9].

This is how foreign sources [10] described the expedition: *"The mission, originally planned for seven days, was cut short due to problems with insulation and some of the equipment. There was also a problem with the winch during the immersion, which caused the habitat to stop at 24 m. This was the saturation plateau depth of the immersion lasting 95 hours. Decompression was achieved by a very gradual emersion over 53 hours and 35 minutes."* This is in conflict with the data provided by the team.

Medical supervision over the mission was provided by physicians from the Institute of Maritime Medicine. The psycho-physical and health condition of the aquanauts after the dive was good [4,7].

From the recollections of A. Dębski and the interviews conducted with him and the other team members, the author concluded that the course of this dive was very dramatic. In order to safeguard life and maintain the pre-set ambient parameters, technically the experiment was carried out as if they stayed in the chamber, through ventilation and the use of an eclectic absorber, which in the decompression phase refused to work due to the saturation of the sorbent. The temperature in the chamber was close to that of the ambient and the divers used the heat generated by their bodies, which, with humidity reaching 100%, did not provide sufficient thermal comfort. Aquanauts themselves carried out activities intended to maintain the pre-set ambient parameters. They measured the oxygen content using the Orsat apparatus, which performed rather inaccurately considering the pressure in the chamber (the apparatus working principle is based on chemical absorption). The composition of the atmosphere was regulated naturally [7].

The reduction in oxygen content was the effect of its natural consumption by aquanauts, which was positive from a decompression point of view. The composition of the atmosphere varied, as the life support function was played by ventilation by air from the surface, very sparse due to compressor failure and malfunction, and from air cylinders stored on Meduza. The air cylinder supplies were constantly diminishing due to leaks. There were many leaks in Meduza and the change in air cushion volume due to the loss of air caused it to sink to the bottom during decompression. The crew managed to restore the buoyancy for which they paid with a great deal of effort and stress as there was a fear of surfacing or braiding the line and not being able to return to the required position deep in the water.

To carry out decompression in accordance with the aquanauts own calculations, 55-minute decompression stops were planned every 3 m, (starting at

21 m). At 9 m, after 2 hours 50' they were to switch to a nitrox mixture with an oxygen content of 37% administered from the cylinder into the chamber. The operation would raise oxygen content in the atmosphere to 28-33%. After 8 hours of decompression at 6 m, the crew was breathing oxygen directly from the cylinder, administered with a hose to the mouth area. During oxygen breaks, the content of oxygen in the atmosphere increased to the levels that prevented the crew from switching to breathing air only at the 3 m stop. Such conditions improved the quality of decompression, but at the same time triggered the risk of oxygen toxicity [5,7,8].

Food for the aquanauts was delivered by assisting divers in sealed 'bubbles' but hot meals were getting cold during this operation. Hot drinks served in thermoses brought the participants of the experiment the only moments of joy and warmth.

After the experiment, scientists and public opinion got divided into two radical groups of strong opponents and enthusiasts of the venture. The experiment received very positive international media coverage. I personally believe that we should not have taken umbrage at the enthusiasts, but instead take advantage of their experience in working in extreme conditions and appreciate their contribution to the then barely fledgling field of saturation diving. Many experts on the subject were outraged at the actions of those carrying out this experiment, accusing them of ignorance and lack of responsibility. In addition, they were upset by the lack of government interference with what had happened. Most of these comments concerned the ex-post reaction after the experiment had received media attention. As asserted by the opponents from the so-called “industry”, the experiment was a sort of club event involving professional doctors unaware of what they participated in. There was also the other side of the coin, where the sensationalist aspect of the case was put aside and those who carried out the experiment got awarded with numerous prizes for their ingenuity and creativity., e.g., with the award of the Supreme Technical Organisation [Naczelna Organizacja Techniczna].

Despite such "primitive" and difficult conditions in which the experiment took place and a series of research and methodological shortcomings, Meduza 1 demonstrated to people from industrial and academic circles dealing with the extraction of resources from the sea and carrying out construction works in the maritime environment, that there is a new and improved tool that offers more opportunities for research in this field. Thus, in spite of the adversities piling up during the Meduza 1 project, passion and imagination have made our country one of the world leaders in solving the problem of prolonged human habitation under elevated pressure.

MEDUZA 2

The next stage, called 'Meduza 2' began shortly after the completion of the experiment with 'Meduza 1'. The Ridging and Underwater Works Company in Gdansk took on the construction of the chamber. Market needs analysis showed that such equipment may be of practical use in various types of long-term underwater work, both at sea and in inland waters. Consequently, the constructors, (this time also led by A. Dębski) designed an underwater habitat larger in volume and offering greater social comfort for three divers. The hull of Meduza 2 was a welded construction of 5 and 8 mm thick steel sheets. It was 3.6 m long, 2.20 m wide and had an internal height of 1.8 m.

Displaced volume - Weight - Weight with ballast
3,750 dcm^3 - 2,950 kg - 8,000 kg - 9 m^3

The volume of Meduza compartment remained within the range of diving bells volumes used for deep dives and saturation diving.

The high pressure section was divided into two parts, one for relaxation (for this purpose the compartment was equipped with berths and a toilet bowl) and the other for work (where the communication system and rope winch were located). What was distinctive of the design was the possibility to use it for classic diving purposes.

The programme of weekly immersion at a depth of 24 m developed by the team participating in the experiment was faced with many legal difficulties. The design of the submersible chamber, the 'submersible habitat' as it was then called, was evaluated by a team of a dozen people from the Maritime Institute in Gdańsk. The programme of submersions was never formally approved or given an opinion. The only evidence of a 'favourable opinion' from the Maritime Institute was a tape recording of a conversation with Dr L. Łaba regarding the planned decompression.

Having overcome many difficulties of a legal and organisational nature and having convinced people around and sponsors, on 9 November 1968 at 18:30 Meduza 2 started to descend at the Hel harbour roadstead. The submersion was assisted by the rescue ship PRO KORAL, from which electricity, compressed air and hot meals were supplied to the chamber crew in special containers. Meduza 2 was larger compared to Meduza 1, with the capacity of 9.4 m, which was sufficient to offer reasonably bearable but still not comfortable living conditions for the three-man crew. The habitat had electric heating and lighting installation, two conventional and one folding berths, sanitary facilities and a life support system capable of sustaining three aquanauts for 50 hours. The ballast in Meduza was operated by a 1.5 t rope winch with the bottom ballast hooked up to the rope.

The winch was operated by a lever operated by the crew inside the chamber, which allowed independent submersion and any depth change. This was important when setting the habitat at the desired depth for decompression. The electrical equipment in the habitat compartment included a 200 W heater, a carbon dioxide absorber with 60 W fan and 25 W lighting. The habitat also had battery packs for emergency purposes. Communication with the diving support vessel (floating base) of the habitat was maintained using wired and hydroacoustic communications. Air and electricity were supplied from the diving support vessel. The electrical supply from the floating base required 24 V from a 400 rectifier. The habitat compartment was equipped with simple devices measuring atmospheric parameters, carbon dioxide and oxygen content (indicator tubes), as well as a hygrometer and thermometer [7,8].

In addition, Meduza 2 had its own compressed air supply in the form of 4 cylinders with water capacity of 40dm^3 (150 atm), and separate 2 cylinders of oxygen for the final decompression phase. The atmospheric regeneration system relied on internal regeneration (CO_2 absorber) and air ventilation. As highlighted in international literature, "the atmospheric regeneration must have been very efficient because one of the aquanauts smoked in the habitation compartment throughout the entire 7-day mission". Conditions in the habitat compartment of Meduza 2 were characterised by low temperatures (around 17° C) at relative humidity of 90-95%, making the atmosphere uncomfortable. It was impossible to take Meduza to 26 m underwater using compressed air only as that would lead to exceeding the allowable oxygen partial pressure. In the experiment this pressure was lowered naturally by reducing oxygen concentration through its consumption by the aquanauts.

In the first period the crew consisted of Antoni Dębski and Jerzy Kuliński. The next day at 11:00 at the depth of 16 m they were joined by a professional diver Bogdan Bełdowski in classic equipment. They spent a night at this depth due to the failure of the winches. The 24 m depth was not reached until 10 November at 15:15 hrs. The depth of the basin at the location of the bottom ballast was 45 m. The wreck of the ship that the aquanauts were scheduled to explore was about 60 m from the bottom ballast and the depth at the wreck was 50 m. The divers left Meduza 2 on a number of occasions to penetrate and explore the bottom and to film the wreck. These missions did not require decompression, but the 4-hour stay underwater originally planned for divers had to be reduced to about 1.5 -2h due to the poor insulating properties of the diving suits [7].

After 159 hours underwater (including 22.5 hours of decompression), the Meduza 2 chamber surfaced at 09:00 on 16 November 1968. Decompression took place at stations located every three metres and longer oxygen stops were made at depths of 9 m, 6 m and 3 m (22.0 hours in total). The tables were developed by Aleksander Lassaud, M.Sc. in collaboration with A. Dębski and Stanislaw Korzeniowski, M.D., as an extrapolation of data from the diving decompression tables.

The aquanaut team included the aforementioned professional diver, an employee of Polskie Ratownictwo Okrętowe [Polish Ship Salvage Co.]. During decompression, the doctor from this company demanded that B. Bełdowski was buoyed up, dressed in classic equipment and decompressed according to the company's decompression protocol in water. There are many theories explaining what this decompression was supposed to look like in practice. Ultimately, the aquanauts rejected this suggestion. After prolonged disputes, decompression was carried out in line with the previously accepted method [7].

The team of divers who supported them on board of KORAL also performed technical and logistical security functions. Its duties included delivering food, filming from the outside and fixing technical faults. Food for the aquanauts was also this time delivered in sealed containers by divers from the support team. As during the Meduza 1 experiment, hot meals were getting cold during this operation. And once again, hot drinks served in thermoses brought the participants the only moments of joy. The team's doctor was Dr Stanisław Korzeniowski. For the time of coming to the surface, Dr L. Łaba, a physician and diver of the Polish Ship Rescue Service, joined the team.

According to historians of underwater diving, this 7-day experiment took place at a depth of 85.3 ft (26 m). Over its duration, the three-man crew worked on the wreck for 4 hours every day at a depth of 164 ft (50m). Interestingly, this time of going underwater corresponds exactly to the modified NOAA-OPS descent times described in Chapter 8 of Miller's Diving Manual (1979). The Meduza 2 project was sponsored by the Ridging and Underwater Works Company and represents one of the earliest working missions using saturation diving.

Decompression time at the end of the mission was 22 hours, less than half the time required for Meduza 1, where the saturation plateau depth was actually 2 m (6.6 ft) greater. The Meduza 2 habitat was most probably used for other projects over the next five years [1].

After the publicity that Meduza 2 received, offers from abroad started pouring in, but they crashed against the wall of insurmountable administrative hurdles. The experiment triggered various discussions about how to improve Meduza 2 so that it could have practical applications in sampling and ground research, as well as ensuring the safety of divers. Among the problems raised by opponents, the main objections were the departure from so-called good diving practice, the lack of a methodology for testing decompression, and the absence of formal basis for saturation diving in general. These problems involved all state institutions dealing with marine economy and leading underwater service companies. Despite the good results of the described experiment and the interest in them that exceeded national borders, Meduza 2 did not immediately find practical application.

The experience of Meduza 2 revealed many aspects of long-term underwater work, such as divers working for many hours in the depths of water, the structural adaptation of the underwater habitat for research work and especially for sampling (underwater drilling), the isolation of the habitat's living compartments from the effect of waves, especially at shallow depths, the identification of autonomy when the floating base cannot be anchored at a stable location above the secured diving site. Another important aspect consisted in adopting formal technical and organisational requirements concerning basic as well as emergency equipment, measurement devices, and the issue of autonomy. Companies willing to use Meduza 2 required full documentation and approved diving methods. Therefore, the next use of Meduza 2 took place in 1972 at the request of the new owner of OBRBWI "Hydrobudowa", in Lake Ostrzyckie. These attempts led to the adaptation of the accommodation compartment for geological works and research, including adaptation for open sea work when one has to cope with high waves of high frequency that threaten to flood the habitat if the upper hatch is open. In parallel with the trials, technical and organisational recommendations were made for the health and safety of diving in, as it was called, the 'diving chamber'. Major changes to the Meduza 2 design included:

- new shape of the compartment and ballast intended to simplify handling and enhance manoeuvring features;
- providing the chamber with an upper hatch and a bottom hatch and a new winch;
- splitting the habitat into living and working compartments;
- changing the connection of the ballast tank,
- adding 100 W headlight;
- adding a towing hook;
- the outer hull was equipped with railings and descent gangway;
- adaptation for use by classic divers.

Safety recommendations were drafted by a physician, doctor Krzysztof Kuszewski, a amateur diving instructor who took part in these trial tests. This was the first document standardising the Polish habitat-related experience and taking so-called 'good diving practice' into account. Many requirements were developed from scratch [6]. Selected recommendations are presented below (original spelling):

- The chamber can be used for underwater works at the maximum depth of 25 m. Divers can work at depths not bigger than 40 m.
- During normal work the chamber is supplied with compressed air from the floating base
- ✓ air must meet the norms for breathing air for divers,
- ✓ there must be a possibility to connect a backup compressor in case of failure,
- ✓ chamber ventilation must guarantee air composition as laid down in the standard.
- ✓ Communication must be maintained between the floating base and the chamber by means of a radio telephone, a diver phone and, in emergency cases, a field telephone. 79
- Control devices in the chamber must allow for the measurement of the following values:
- ✓ pressure inside the chamber, the depth of submersion, CO_2 content in the chamber, CO content in the chamber, humidity, temperature, time; pressure in the chamber must also be controlled from the diving support vessel.
- A device that identifies the depth of the chamber submersion must be provided with additional emergency equipment (the second winch).

Ensuring security and safety of diving operations,

- ✓ Air compressor for filling diving cylinders and 10 cylinders
- ✓ The chamber must be fit for being supplied with oxygen
- ✓ A stock of 10 40-litre cylinders with compressed air and 2 40-litre cylinders with medical oxygen,
- ✓ The floating base must be equipped with portable oxygen inhaler that can be used to transport an injured diver.
- ✓ If possible, the floating base should also be equipped with a decompression transport chamber.
- Chamber crew work 8 hours a day, including the time of preparations. A single descent of a chamber may not last more than 90 minutes.
- in the chamber 4-hour watches are performed around the clock.
- Crew decompression must follow a pre-set protocol. It shall proceed under the supervision of a physician whose decisions are final. Before the start of underwater works, the physician is obliged to specify details of the hospitalization of divers (where, means of transport, communication).

Meduza 1 and Meduza 2 dives were by definition saturation dives. When used commercially, the Medusa 2 dives could be called transient or short duration dives with divers spending long time under pressure. Exposure time at working depths was several hours (between 4 and 10). At the time, this type of diving was referred to as 'sub-saturation dives'. What was the reason for this arrangement? According to the author, the following factors contributed to it:

- research works required the habitat to be moved to another position, which in turn required the habitat to ascend to the surface and be repositioned. One needs to bear in mind that
- Meduza 2 position in the depths of water was achieved through the ballast adjusted by a rope connecting the habitat compartments,
- working and resting conditions of the divers in this habitat did not provide them with full comfort,
- sampling was a strenuous work, which required team shifting,
- lack of belief that this type of diving is really necessary although there was demand for such long underwater works,
- at shallow depths the service using the habitat was not economically viable.

Meduza 2 habitat was used in the construction of the Port Północny (Northern Port) in Gdańsk. This project required divers to work at shallow depths of up to 20 m. The work involved taking samples of sediment cores from the bottom and testing the hardness and bearing capacity of the bottom before and after explosion hardening. Meduza 2 also worked for the Geological Institute in Sopot in the Baltic Sea in the depth zone down to 60 m (at the time, this depth was the maximum up to which air could be used as a breathing medium) for bottom sampling aimed at searching for rare minerals [4].

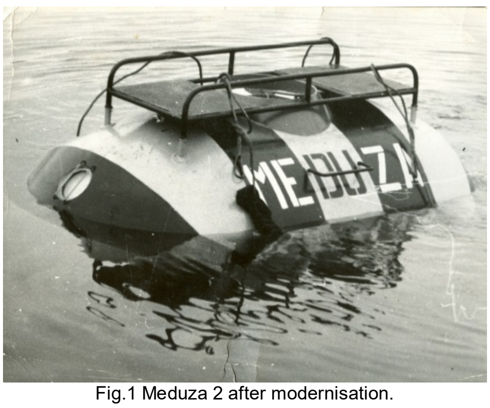

Fig.1 Meduza 2 after modernisation.

GENOUR I 1975-1980

The shortcomings and defects of Medusa 2 were to be remedied by the next generation habitat for deep-sea drilling, designed under the auspices of the Polish Society of Friends of the Earth Sciences (Polish abbr. PTPNoZ). Geonur was designed by Antoni Dębski and built at the Gdynia Shipyard on order of the above-mentioned Society. In practice, it turned out that drilling works underwater could continue as long as the floating base could supply electricity. In other words, it depended on sea condition decisive for anchoring.

The shape of this habitat was adapted for impact drilling and resembled that of a cased drilling rig. Thus, an underwater drilling rig was designed that was 8 m high, 4.20 m wide at the base, a working chamber width of 3 m, a total displacement of 33 T and a total weight of 24 t. Geonur 1 was intended to solve the problem of drilling at medium depths and additionally to be used for salvage, construction and remedial operations, as well as to support biological, archaeological and physiological research. Geonur (a 'geological diver') four-person habitat was to be capable of staying for several days at depths of up to 164ft (50 m). The habitat included a working compartment for drilling, water ballasts and a decompression chamber. The decompression chamber was connected via a lower hatch with the depth of water, via an upper hatch with the surface and via a third hatch with the drilling shaft. With the ballast tanks blown negative on the water surface, Geonur 1 assumed a 45 degree inclined position, which facilitated towing and acted as a shock absorber for the tow. Breathing gas was supplied from the diving support vessel, although the habitat contained a 30-hour independent life support system. Communications were maintained by cable telephone and radio via coaxial cable, buoy and antenna.

While working at sea, the diving support vessel was often forced by storm conditions to dump the cable tow and air hose on a prepared pontoon. In such cases, Geonur 1 crew would switch to their own power supply and, once the drilling was complete, the habitat would be brought to the sea surface, maintaining the necessary pressure inside for a given period of decompression. Geonur 1 could wait out the storm on the bottom or be towed to port and carry out decompression while being towed [11]. One of the primary objectives of its design was to avoid the impact of the most dangerous factor at sea, the wave action, and in particular its effect on the pressure change in the habitat compartment. At a wave height of 1m, the pressure periodically increases and decreases by 0.1 bar, which affects the escape of the atmosphere and, worse, adversely irritates the diver's vestibular system. This phenomenon becomes less and less noticeable with increasing depth. Geonur 1 was tested offshore in wind speeds up to 26 knots. At the time of its construction, the aim was mainly to drill to depths of 20 – 30 m below the bottom. Given the region of the southern Baltic Sea and its almost constantly undulating surface, any drilling from pontoons and floating vessels was very expensive and stretched by the extended time of waiting for good weather. The designers envisaged submerging this habitat together with the drilling rig, with all the equipment, and placing it on the bottom.

The time spent by divers underwater varied, depending on the structure of the bottom, which dictated the drilling time. The shortest dive including decompression lasted 18 hours. Other ranged from 48 to 96 hours. In 1976, the Geonur enabled an expedition to the wreck of the 'Wilhelm Gustloff' lying at a depth of 46-49 m, which was made famous by the mass media (search for the Amber Chamber). The total time spent in Geonur 1 was nearly 47 hours of which decompression took more than 15 hours. During this time decompression followed the sub-atmospheric dive tables developed by A. Dębski, and by a group of people from abroad interested using tables of using air [11].

Geologists described the Geonur as a 'floating drilling rig' whose design was the first of its kind in eastern Europe. It carried out many underwater probing tests, mainly in ports, shipyards and shipping lanes. Geonur 1 terminated its existence in Atlantic waters at the mouth of the Senegal River on the St. Luis traverse, where it was to carry out drilling close to the undertow. The surveys were necessary for the planned construction of a seaport in the area. As a result of an error on the part of the transport vessel, Geonur was thrown ashore by the undertow and damaged, resulting in it becoming unfit for further use [12].

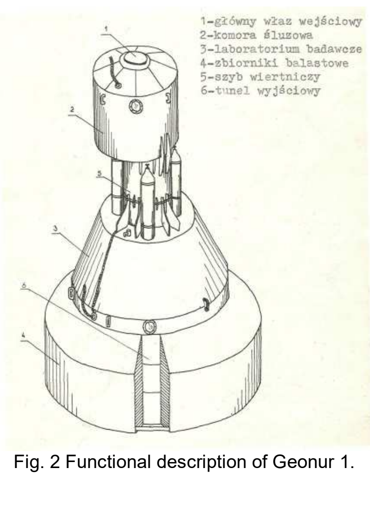

Fig. 2 Functional description of Geonur 1.

GENOUR 2 1981- 1984

The experience gained and needs dictated the construction of a more versatile and multifunctional device. Acting on order of the PTPNoZ, the Gdynia Shipyard built Geonur 2 in 1981. The main designer was again A. Dębski. The project envisaged a very versatile use of the bathyscaphe, e.g.:

- direct observation and underwater laboratory tests,
- studies on the contamination of bottom sediments and water at different depths,
- drillings down to 30 m from the bottom,
- underwater rescue, assembly, search, and filming operations,
- research works in the physiology of diving,
- research effort requiring independent moving around in the depths of water.

Plans also envisaged that Geonur 2 would serve as an underwater base for diving, drilling, inspection of cables and underwater structures in Polish ports, and as an observation platform from which data on the marine environment could be collected.

The Genour 2 was also used to map bottom mineral deposits in the southern Baltic. It was assumed that the crew would consist of up to eight people [4,5].

One could write a fascinating book about the obstacles, adventures and emotions surrounding the launch and use of the Geonur. On this winding road full of barriers, the protagonists were opponents, enthusiasts, state agencies, sponsors and supervisory institutions. This was mainly due to the lack of regulations and preparation of supervisory institutions, the ambivalent attitude of scientists and the intransigent, goal-oriented character of the chief designer.

The streamlined hull allowed Geonur 2 to optionally float on its own and facilitated towing.

Technical and operating data of GEONUR II:

Dimensions:

- length 9.65m
- width 4.4 m
- height 4.3 m or 7.1 m with the drilling rig
- total displacement 66.0 – 67.7 m^3
- weight without permanent ballast 21 t
- submersion 2.0 m.

Exploitation data:

- crew 2 - 8 people,
- air and oxygen for 4 people for 150 hrs.
- According to the plan, the drive was to consist of a pack of batteries ensuring continuous operation of the engine for 4 hours, but the plan was abandoned for obvious time-related reasons and the lack of money.

Geonur 2 was prepared for the installation of a mixture system for depths of less than 60 m, as it was to work on pipelaying in the southern seas [8]. Four trimming tanks were located in the base to further enhance stability when the habitat was anchored to the seabed. It had, like a submarine, two hulls. One strong pressure hull and one light hull, consisting of 4 ballasts, whose volume allowed it to take 28 tonnes of water. The strong (pressure) hull was divided into a living area, a room for divers and a decompression chamber, and the engine room, which was the working space. It had three compartments, a drilling compartment with a movable drilling shaft raised by internal pressure and a separate small compartment for the drive. It was clad with four sections of ballast and two stabilising floats, fitted after trial dives to improve stability. The hull had three hatches, a lower one for drilling, an exit to the deck and one in the shaft. The life support system relied on its own air supply and a mobile measurement and carbon dioxide absorption equipment.

There were enough supplies on board to keep four people alive for seven days. After completing manoeuvring tests and submersions under the supervision of the Polish Register of Shipping to a depth of 60 m, the bathyscaphe received a safety passport from the Maritime Office. This meant that Geonur 2 was authorised for operation in mid-1982. The sea trials of the bathyscaphe were secured by the Navy rescue ship R-23.

The Geonur 2 bathyscaphe was designed as a diving base up to 150 m depth, and as a drilling rig up to 80 m when seated on the bottom. Conversion of the bathyscaphe to a drilling rig could be achieved by removing the screwed-on bottom of the kiosk and fitting a telescopically extendable drilling shaft in its place. Financial shortages forced savings. As a result of the country's economic hardships and the embargo imposed by the Western countries, very simple equipment for the Geonur installations sometimes had to be acquired through unofficial distribution channels. In fact, as a result of financial shortages and the requirements of PTPNoZ, a supply of air was prepared for work at depths of 20 – 24 m to secure surveys and geological assessment of gravel resources on the Słupsk Shoal. The works consisted in drilling and bottom sampling carried out to assess gravel resources for industrial use in the construction sector as part of the government programme intended to mobilise the economy of the Polish coastal region.

Fig. 3 Geonur 2 at the shipyard.

Several dozen of boreholes were drilled in the Baltic Sea at depths of up to 30 m and 10 - 20 m below the bottom from the Geonur deck, mainly in 1983. The works were secured by the PRO Jantar rescue vessel. Many divers from scuba diving clubs and professional divers, geologists, hydrogeologists, geophysicists and other experts took part in the operation of Geonur 2. Their work was secured by medical doctors from the Central Institute for Labour Protection. The Geonur work was of interest to the Naval Rescue Service as an underwater vehicle was needed for rescue purposes, also for rescuing submarine crews [4,5].

On Geonur 2, like on Geonur 1, sub-saturation diving, as it was called at the time, using air and oxygen was used. When it comes to decompression, Geonur 2 was equipped with a full system of decompression tables. The primary tables were the decompression tables for sub-saturated dives, while the emergency tables were those for air-oxygen saturation dives. For trips from the saturation plateau of 14, 16 and 18 m down and up, and in the event of a decompression incident, therapeutic recompression tables with oxygen were included. Decompression tables were signed by the Central Institute for Labour Protection in Warsaw, using available international literature.

SUB-SATURATION DIVING

Technical capabilities of the Polish habitats and administrative resistance prevented the use of saturation diving in underwater works. Therefore, decompression was used for, as it was called at the time, sub-saturation dives. The term sub-saturation diving was used in the 1960s and 1970s for the decompression theory of diving [13]. This type of decompression was used in Meduza 2 and habitats designed in later periods for underwater drilling by the impact method, Geonur 1 and Geonur 2. In sub-saturation dives, divers worked underwater for several hours (from 4 to 6 hours) going out to work in the water and returning to the habitat living compartment for rest, or working only in the working compartment to complete decompression after the working day, once the habitat was brought to the surface (or, as was the case with Meduza 2, setting decompression stops in the water). There were special decompression tables dedicated to sub-saturation diving with the depth of stay limited to 18 m. From this depth, divers plunged to the working depths from Meduza 2. Divers' work in Geonurs was similar to that of the caisson workers, the difference being that the 'caisson' was towed and submerged at a specific site underwater with research work taking place mainly in the working compartment, and divers submerging underwater through the lower hatch only if necessary.

What sources of information did the pioneers of Polish sub-saturation diving have at their disposal? At that time in Poland there was one and only one piece of legislation concerning decompression after long time exposure to pressure. This was the Regulation of the Ministers of Labour and Social Welfare and Health of 2 June 1952 on safety and hygiene of work in caissons. It stipulated the maximum time of work at 'overpressure up' to 3.5 atm (original spelling) for a loosening time of 60 min. What was missing was the definition of working time under excess pressure, which was laid down in Resolution No. 718 of the Council of Ministers of 26 October 1954 on the reduction of working time for caisson workers. Thus, within one day of working at overpressure conditions, a worker may not work longer than 7 hours at up to 1.75 atm, 6 hours at the pressure between 1.75 atm and 2.5 atm, 5 hours at the pressure between 2.5 atm and 3.0 atm, 4 hours between 3.0 atm and 3.5 atm, and 2 hours at the pressure ranging from 3.5 atm to 4.0 atm. In addition, data concerning this subject was supplemented with data from Western countries [1,14]. Data from decompression air emergency tables from the Polish Navy tables were also taken into account.

Within a broader term of underwater work, two types of divers' work were distinguished. The first covered divers working in the water depths and the second those working on board of the habitat without leaving it. Working on board of the habitat was allowed for up to 12 hours at the depth not exceeding 36 metres. In this option, work organisation is simple, as according to the tables for sub-saturation dives, one dive is sufficient. Staying in the depths of water or handling of the sampling equipment was strictly limited to a few hours and was followed by a long decompression. The same was true when a diver worked outside the habitat but at depths permitted by the tables, in the depth zones included in the tables for sub-saturation diving, e.g., when a habitat was seated at 14 m and the diver worked at 20 m. Guidelines for sub-saturation and saturation diving stated that the diver's work should be planned taking into account the time for resting and vigil on the saturation plateau (sub-saturation) [15].

The safety instructions stipulated that each time a diver returns from working at increased pressure to the relaxation pressure, an examination should be carried out within the first 5 minutes using an ultrasonic venous gas bubbles detector. If there are signs of bubbles, recompression to relief pressure should be carried out in line with rules described in further sections of the instructions, followed by a reduction in pressure to relaxation pressure at a rate of 0.5 m/min, if necessary with the use of appropriate decompression stops according to the table. A diver experiencing such fatigue symptoms should be relieved from further work at pressures greater than the saturation plateau pressure. Decompression tables for sub-saturation dives using oxygen predicted decompression up to 5m/min and a transition time from stop to stop of 1 min. The tables also provided for extended decompression, in which the expansion rate was reduced to 0.5m/min and the transition time from stop to stop lasted 6 min. In some cases, it may have been necessary to work at pressures lower than the saturation plateau, and such situations were covered by the diving trip rules outlined below [15] (Table 1).

The tables provided for diving trips at depths greater than the saturation plateau provided in the table. Dives longer than 12 hours are classified as saturation diving. As already mentioned, when using the tables for sub-saturation diving one may work only without exceeding the depth range included in the tables, and at a pressure below the saturation plateau.

Tab. 1

Selected decompression methods using air and oxygen for sub-saturation diving at operating depths applicable for Meduza 2 and Geonurs [15].

Operating depth	Time underwater	Time to the first stop *(extended decompression)*	Decompression time at stops				Total decompression time	Total time of extended decompression
Depth of stops			12m	9m	6m	3m		Depth of stops
[m]	[hour]	[min]	[min]	[min]	[min]	[m]	[hour]	[min]
9	6	2 (x)				8	11	X
	8	2 (12)				14	17	28
	12	2 (12)				23	26	41
12	6	2 (x)				16	19	x
	8	2 (18)				28	31	52
	12	2 (18)				46	49	70
18	4	3			2	53	60	x
	6	3			14	680	99	130
	8	3			31	99	134	165
	12	2		-	51	60+p30+50	198	229
24	3	4			26	63	95	X
	4	3		4	36	82	128	170
	6	3		20	60	30+p20+30	210	253
	8	3		40	30+p20+30	80+p30+30	265	307
	12	3	12	45+p15+20	60+p20+25	80+p30+30	343	385

The tables required that the working time of a diver outside the habitat could be a maximum of 2 hours, the working time in the working compartment 4 hours (if working in 2 shifts). For light work the time could be extended to 6 hours. Work outside the habitat should take place under constant pressure providing that changes in working depth exceeding 33% of the difference between the pressure at the plateau and the pressure at the work site should be avoided.

Tab. 2

Air decompression table for sub-saturation diving used in exceptional cases. Decompression rate up to 5 щ/min [15].

Operating depth	Time underwater	Time to the first stop	Decompression times at stops				Total decompression time
Depth of stops			12m	9m	6m	3m	
[m]	[godz]	[min]	[min]	[min]	[min]	[min]	[min]
9	6	2				12	15
	8	2				21	24
	12	2				35	38
12	6	2				23	26
	8	2				41	44
	12	2				69	72
18	4	3			2	79	86
	6	3			29	119	144
	8	3			44	148	197
	12	2			76	185	270
24	3	4			38	94	138
	4	3		6	53	122	187
	6	3		29	107	160	285
	8	3		59	107	187	359
	12	3	17	108	142	187	461

Such decompression tables designated for use in sub-saturation diving were based on the NOAA-OPS tables described in Chapter 8 [1,14]. These tables distinguished between four saturation plateau depths: 9.1 m, 18.3 m, 27.4 m, and 36.6 m. From these saturation levels, trips to greater depths were conducted both without decompression and with decompression to return to the saturation plateau. As examples we can use selected methods that were used in Geonurs presented in Table 2.

Tab. 3

Working depths permitted at pressures greater than the saturation pressure depending on saturation plateau level and maximum time outside of Geonur. Use only if time spent at Geonur exceeds 12 hours. Resting time for divers before starting decompression 12h [15].

Saturation depth	Maximum working time under pressure [min]	30 [min]	60 [min]	90 [min]	120 [min]	180 [min]	240* [min]	360* [min]
14		59 m	55	50 m	29 m	27 m	27 m	27 m
16		45 m	57	34 m	32 m	31 ж	31 ж	31 ж
18		47 m	40	37 m	35 m	54 m	54 m	54 m

Tab. 4

Emergency table. Decompression for saturation plateau 18 m using air and oxygen.

Stop depth [m]	Transition time [min]	Time spent at the stop and type of mixture [min]	Total decompression time [min]
16.0	15	Air	15
9.0		Air 160 oxygen 30	205
	5		210
7.5		Air 165 oxygen 30	405
	5		410
6.0		Air 165 oxygen 30	605
	5		610
4.5		Air 20 oxygen 30 Air 20 oxygen 30 Air 20 oxygen 30 Air 20 oxygen 40	810
	5		815
3.0		Air 60 oxygen 30 Air 20 oxygen 30 Air 20 oxygen 30	1015
	5		1020
1.5		Air 200	1220
	5		1225

Total decompression time 20h 25min including the total time of breathing oxygen 335 min.

The sub-saturation diving system was a complete one and conformed to current standards for decompression for commercial diving. It included a basic (working) table and a table for extended decompression. The safety manual was supplemented by tables for exceptional exposures, including trips to depths greater than the plateau (Tables 2 and 3). Emergency tables were saturation tables for three depths, to be used after a 12-hour stay on the plateau had been exceeded. These tables were provided for the three depths at which air could be used for plateau saturation of 14 m, 16 m and 18 m (e.g., Table 4). In addition, the system included therapeutic recompression tables based on the US Navy tables 5 and 6, and French C_x30 using nitrox 60% O_2 40%N_2 air and oxygen.

CONCLUDING REMARKS

Quoting after A. Dębski from a panel discussion held on 25 February 1975 and organised by the PTPNoZ "*When listening to what has been said here just now, a thought occurred to me that has been haunting me for a while. It is of course right to discuss what we can do, what resources we have and we should consider that. But how did we do it in Poland in the field of batynautics in general? This is Medusa 2, it is the cheapest piece of equipment compared to any type of conventional diver's work.*" The world of underwater work signed up to these words in the decades that followed, introducing saturation diving into commercial and defence activities. The forerunners and pioneers of saturation diving operated in difficult socio-economic conditions but have successfully made their ways to the world history of diving. In the times of their activity the outcomes of their work were received with mixed feelings ranging from euphoria to the negation of the path they had taken. They showed that they had passion and character which was not accepted by renowned research centres. Contrary to the common logic and despite relying on simple technical solutions put in place without any research backup, or physiological and decompression processes that were not fully understood at that time, they succeeded in introducing a new approach to underwater work and managed to commercialise it. To this day, no distant negative health effects have been found in the divers involved in the described activities and the protagonists of these breakthrough events were and are blessed with long lives.

My adventure with these enthusiasts began in the 1970s and I was shocked by the burden of formalities involved in the diving activities performed by the Navy. I admired the enthusiasts and the people supporting them for their ability to convince other people to support their idea and their ability to solve problems in a creative, imaginative way. With this article, I would like to praise their efforts and pay tribute to them. I would also like to thank them, as I have benefited a lot from what they have accomplished in my professional career when working on the underwater environment.

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