STUDIES ON SATURATION DIVING IN POLAND AND PRACTICAL APPLICATION OF THEIR FINDINGS. PART 2 B. DEVELOPING A POLISH SYSTEM OF SATURATION DIVING IN THE 1980S AND 1990S

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ABSTRACT

This article is another in a series of articles on the research and the deployment of saturation diving technology in our country. This part discusses Polish specificities and achievements against the background of economic and historical context. It describes the creation of the base for saturation diving in the times of economic hardship in our country. Over this period, the shipbuilding industry was driving saturation diving research as a basis for the construction of diving systems to be exported to secure the extraction of the resources from the sea shelf. This paper describes the efforts of the animators and protagonists of underwater research in our country, whose work is continued to this day. In its second part the author shows how the Polish system of saturation diving was created. The article also considers the technical and organisational conditions in which the first saturation dives took place and the history of the development of the Polish decompression method for saturation diving. A key role in this difficult task was played by the creation of a base for this industry and research potential, assisted by the relevant state agencies, dedicated for the defence sector. A multiannual National Research and Development Plan (Polish abbr. CPBR) was set up with objectives 9.2 and 9.5 focused on medical and technical research resulting in the development of a diving system with its organisational framework, medical safety solutions, and reliable technology. The outcomes of this programme are still being implemented today. Despite advances in the medical and technical fields as well as organisation, the problems of saturation diving are still pertinent because, regardless of its complexity and high cost, this is the most efficient diving format that allows for very deep diving operations, currently up to 400-500m.
Keywords: diving research base, implementation of saturation diving, medical and technical problems of divers' decompression, saturation diving, diver life support systems, diving system, saturation diving, decompression tables, diving organisation, nitrox, trimix.

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CONSTRUCTION OF A SATURATION DIVING RESEARCH BASE BETWEEN 1980 AND 1987

The Polish research base for diving medicine, technology and organisation started to develop in the 1960s. The development path depended on the solving of problems, which were popping up along the way. A spectacular example is the research work related to the problems of saturation diving. The already existing hyperbaric chamber unit at the Naval Academy adapted for standard dives up to 60 m was used for the purpose of research, development and the dives themselves. The unit was first modernized to fit air saturation dives to a depth of 20 m.

Subsequently, the base was developed for saturation diving with nitrox mixtures, which required more extensive development of measurement technology, medical research as well as research into safety technology. In parallel, the qualifications of the research, medical, technical and diving staff were improved and organisational aspects were streamlined together with formal requirements. Based on the results of research and experiments in saturation exposures with nitrox, work was undertaken on the final shape of a research base for all types of research intended for a depth of 100 m. Considering the demand for saturation diving at sea shelf depths, a base was developed using the existing diving unit at the Naval Academy as the starting point. In the early 1988, following interruptions in programme funding caused by economic perturbations in the country, the construction of an experimental deep-water diving unit for a maximum depth of 120 m (DGKN-120) was finally completed. The maximum operating depth of 120 m water column resulted from the pressure characteristics of the component chambers of the new unit adapted to the depth of the sea in the Polish economic zone.

The research mandatorily required proper technical protection for presumed emergency situations and conditions. Any emergency procedures used in diving technology had to be realistically considered in the technical, medical and organisational structures used in the research diving unit. In both manned submersible facilities and diving technology, emergency procedures must be in place prior to the research and training of the research team. State institutions engaged in the multifaceted cooperation and - while solving the problems of commissioning the DGKN-120 - took on the solution of the technical problems related to the design and practical implementation of life-safety systems for deep-sea operational units of the GWK- 200 and LSH-200 types. These diving complexes were manufactured at the Szczecin Shipyard. A full research and development cycle for them was carried out based on the use of DGKN-120 hyperbaric chamber experimental base established, among others, within CPBR- 9.5 objective 31.

CHARACTERISTIC OF THE EXPERIMENTAL DEEP SEA DIVING UNIT (DGKN-120) [1]

The DGKN-120 unit consists of a set of hyperbaric chambers, auxiliary systems, and equipment, that ensure the required conditions for saturation diving.

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Although at the time, the diving regulations in force covered dives carried out using artificial respiratory agents, the lack of appropriate technology did not allow such dives to be performed. These regulations failed to address or even mention saturation diving. Permitted by the regulations at that time, oxygen decompression, which was and still is the basis for treating specific diving illnesses with recompression, was not generally used for technical reasons. Due to barriers to international exchange, virtually all equipment was made from scratch using domestic components and resources. Deep dives with heliox in the Navy were performed on an experimental basis using US Navy decompression tables and Dräger diving equipment. These were the only experiments with heliox mixtures in our country.

The hyperbaric chamber unit consists of three interconnected chambers, aligned horizontally to each other. They are designed to fulfil the following functions:

- chamber No. 1- training chamber,
- chamber No. 2 – entrance-transfer and sanitary facilities,
- chamber No. 3 - living (sleeping) area.

To enable the operation of the chambers at the assumed technical and medical parameters, the following equipment was developed, tested and manufactured at the Naval Academy:

- systems for measuring the parameters of the chambers' atmosphere;
- systems for regeneration and air conditioning of the chamber's atmosphere;
- sanitary facilities;
- control panels in the chambers;
- diving unit control station;
- gas analysis laboratory;
- emergency breathing systems for breathing mixtures and pure oxygen;
- communication systems with speech correctors for helium atmosphere;
- CCTV systems to be able to watch the divers in the chamber;
- chamber lighting systems;
- operational and astronomical time measurement devices;
- continuous recording system for the chamber atmosphere;
- breathing mixture production and storage systems;
- systems for supplying breathing mixtures, pure gases, air and oxygen to the chambers;
- systems for the removal of mixtures from the chambers and their storage;
- medical monitoring systems for the divers' vital parameters in the chambers;
- emergency power supply systems for the unit.

As a result of the design and research work carried out, the following technical parameters were achieved for the DGKN-120:[1,2];

- maximum total pressure of the chamber assembly - 1.25 MPa;
- the range of pressure increase rates - up to 100 kPa/min;
- minimum intended rate of depressurisation of the chamber - 0.2 kPa/ min;
- maximum capacity of the oxygen supply system

(per chamber) – 42 dm^3/min;
- accuracy of maintaining partial pressure of oxygen within the range (20 - 140) kPa-±(1-2) kPa;
- measuring range of COr percentage - (0- 0.5 - 2) %;
- accuracy of CO2 measurement - ±0.005 %;
- temperature control range inside the chambers (18-25) °C; with an accuracy of ± 1°C;
- relative humidity control range inside the chambers with an accuracy of ± 10 %- for a range (40 - 80) %;
- operating time of one atmosphere regeneration system without exchanging sorbents - 120 h;
- habitability for long-term stay in the chamber - 3 divers;
- number of emergency mixture breathing stations in each chamber - 4;
- total volume of pure gases and mixtures that can be stored in the stationary tanks - 3750 Nm^3;
- volume of chambers - 45 m^3, of which:
- ✓ entrance chamber 10 m^3,
- ✓ sleeping and living chamber 10 m^3,
- ✓ training and research chamber in the dry part 23 m^3, including the pool 5 m^3 in the wet part.

The gas storage and breathing mixture generation system was equipped with;
- 5 pressure vessels V=1 m^3 p=150bar with 4 in each section,
- 4 air release tanks V=10 m^3 p=30bar,
- compression unit consisting of:
- ✓ compressors for helium and oxygen,
- ✓ two compressors: a high pressure and a medium pressure high capacity,
- ✓ air filtration system,
- ✓ gas distribution panel.

The gas storage and mixture generation system enabled:
1) pumping and storing pure helium, nitrogen, diving air, oxygen and two types of gas mixtures at pressures up to 20 MPa,
2) preparation of gas mixtures (oxy-nitrogen, oxy-helium, and oxy-helium-nitrogen) up to 15.0 MPa,
3) obtaining compressed diving air at pressures up to 15 MPa.

The amount of gas stored within the unit allowed for up to 30 days of diving without the need to replenish gas stocks, as well as a minimum of two quick refills of the chambers up to full operating pressure.

The oxygen transfer and pumping system is equipped with ramps, pressure vessel sections, oxygen transfer machines and performs, among others, the following tasks:
- oxygen transferring and pumping from transport cylinders to emergency portable cylinders and to other transport cylinders,
- oxygen transferring and pumping from transport cylinders into stationary mixture tanks to prepare mixtures or increase pressure for operational purposes.

The construction of the central respiratory gas systems allows to supply the chamber in a hyperbaric chamber unit in parallel with:
- inert gases, i.e. helium and nitrogen,
- ready-made breathing mixtures,
- mixtures of the required composition, prepared directly in the chamber in which the divers are housed.

This was done using upgraded operating panels' of the individual chambers.

The hyperbaric chamber unit is equipped with an emergency supply station for the supply of breathing mixtures and pure gases to the chambers. The emergency station consists of a system of interceptors and regulators adapted for the direct connection of typical transport cylinders (20 at a time) of pure gases or mixtures prepared in them. It is located directly adjacent to the building that houses the chamber unit, and used in the event of an emergency situation when the main stationary tanks must be cut off from the supply systems. When ‘saturation’ takes place in the unit, this system is always ready for immediate use.

Flexible pressure vessels were installed for the recovery of helium and mixtures. Their design ensured the recovery of mixtures discharged from the chamber unit during depressurisation (decompression), as well as from emergency breathing systems - from the exhaust line. "Spent" mixtures were stored in stationary pressure recovery tanks with special systems to transfer and pump them. It was also possible to remove the products of metabolism, such as carbon dioxide, moisture and other impurities from the recovered mixture.

The entire technical infrastructure of the DGKN-120 diving complex covers an area of approximately 3,000 m^2

The diving unit is also equipped with emergency power supply equipment and installations. This equipment is switched on in the event of a power failure in the municipal network.

The DGKN-120 unit had a data recording, astronomical and operational time measuring system for mapping the dive and especially decompression.

The Naval Academy owned and still owns the only Experimental Deep Sea Diving Unit in the country permanently modernised and adapted to perform research tasks. Through the research and implementation work carried out, as well as design and construction work, it was possible to train engineering, technical and medical personnel capable of researching the whole range of medical, technical and organisational issues associated with saturation diving.

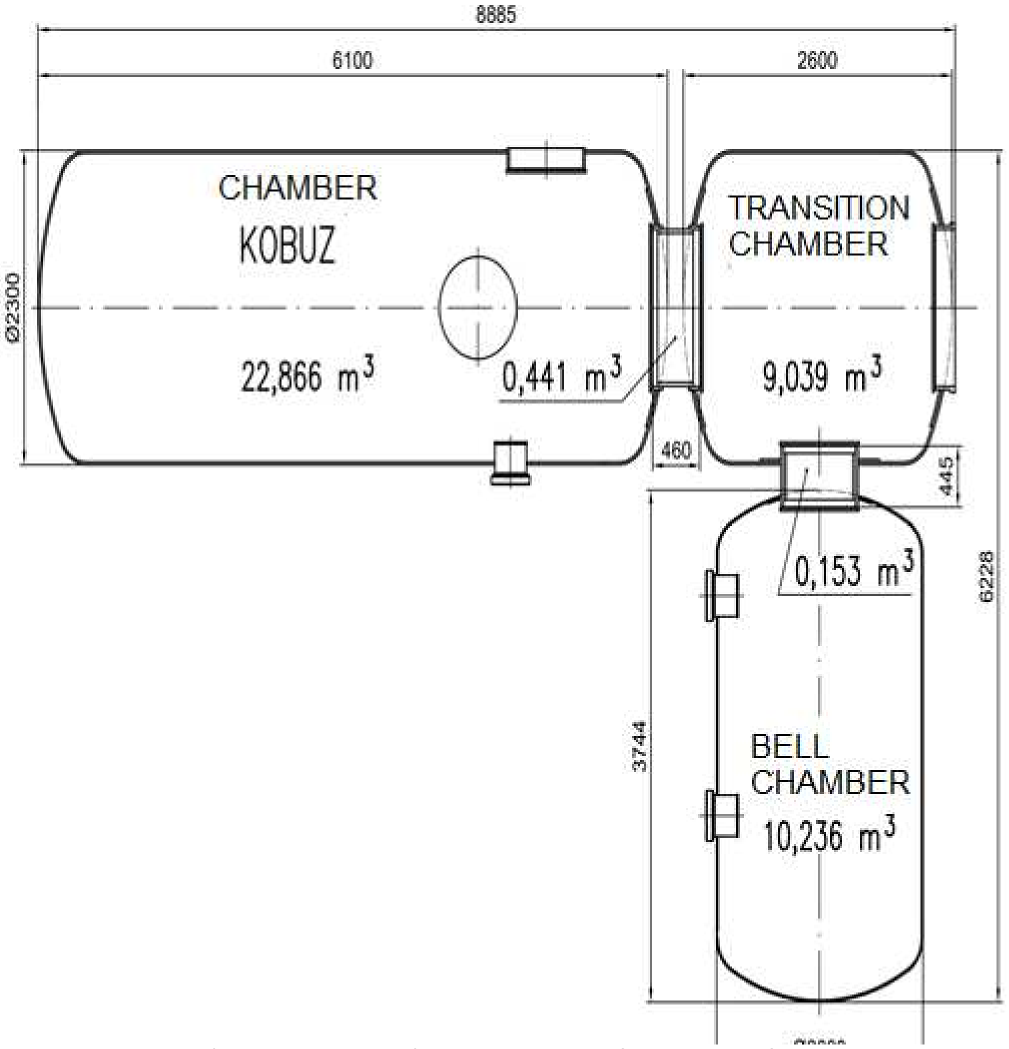

Fig. 1 The layout of hyperbaric chambers of the Experimental Deep-Sea Diving Unit DGKN-120 at the Naval Academy.

STUDIES OF SATURATION DIVING WITH NITROX 1985 - 1987

Poland is one of the pioneers of the use of nitrogen-oxygen mixtures in saturation diving. Experiments with Medusa chamber in the 1960s and 1970s carried out in primitive conditions with continuous air ventilation resembled working in a submarine compartment with 100% humidity and air. In short duration dives, it is reasonable to use nitrox with an oxygen content of more than 20%, to improve and shorten decompression. On the other hand, in saturation diving with nitrox, we use hypoxic nitrox mixtures containing between 8 and 14% of oxygen for saturation plateau depths of 40-20 m. Diving technologies using nitro-oxygen mixtures have been developed and used by the Department of Diving Equipment and Underwater Work Technologies of the Institute of Ship Design and Propulsion of the Polish Naval Academy, with the medical cooperation of the Department of Underwater Medicine of the Institute of Maritime Medicine of the Military Medical University (Polish abr. IMM WAM). Technologies applied at depths 20 – 45 m were used for CPBR-10.1 – on order of the Institute of Maritime and Tropical Medicine in Gdynia, where the team of divers-testers was trained.

The diving technology must fit the technical base and be compatible with the system of safeguards in force in the country. In Poland, a system of standard and deep-sea diving for submarine crew rescue purposes, including technical and medical protection and diving bases, was operated by the Navy. Saturation diving with nitrox was complementary to emergency procedures when using air diving.

Between 1986 and 1987, a series of 6 saturation dives was carried out on nitrox mixtures (nitrox) at depths of 20-30 m, grading saturation plateau depths every 2 m. In the same years, a series of 4 saturation exposures at depths of 30-45 m also took place, grading saturation plateau depths every 5 m. Pure nitrogen was used during compression, 'diluting' the oxygen so that its partial pressure of 0.4 ata was achieved at the decompression plateau. The stay at the plateau lasted two days. Decompression was then initiated. Decompression is relatively 'fast' in the first phase and then between 28 m and 20.5 m it continues at a rate of 0.5 m in 62 min; between 20.5 m and 15.5 m, 0.5 m in 64 min. Then decompression slows down to reduce pressure at a rate of 0.5 m in 134 min at depths from 1.5 m to 1.0 m (see Table 1).

Tab. 1

Decompression table for saturation diving using air from saturation plateau 18 m [3].

Stop depth [m]	Return time [min]	Time at stops and gas mixture [min]	Total decompression time [min]
18.0	15	Air	15
12.0		Air 90 oxygen 10	115
	5		120
10.5		Air 165 oxygen 20	305
	5		310
9.0		Air 355	665
	5		670
7.5		Air 75 oxygen 30	775
	5		780
6.0		Air 115	945
	5		950
4.5		Air 115 oxygen 50	1115
	5		1120
3.0		Air 165	1285
	5		1290
1.5		Air 105 oxygen 60	1455
	5		1460

Such speeds at low pressures gave rise to numerous technical problems. These ranged from ensuring the tightness of the hatches, which depends on the pressure in the chamber (more pressure means that a large diameter hatch sealed with a flat seal made of hard rubber is pressed more tightly), sampling for gas analysis, the work of the sanitation equipment and measuring the pressure drop at 6 mm H_2O water column per minute. Decompression for nitrox is a continuous process, i.e., it goes on without the overnight sleep breaks, which feature in all decompressions with the use of heliox. It required very sensitive pressure gauges, as a reduction in chamber pressure of 0.5 m water column in 85 min on the lowest levels is almost imperceptible. This is beyond the sensitivity scale of modern manometers used in diving systems for decompression for the range of 0-25 m in which the measurement error is ± 5cm. For continuous decompression, the change should be 0.6 cm per minute. The decompression requirements were met despite measurement difficulties at shallow depths. A resonator pressure gauge was developed to solve this problem. Its accuracy was 10 Pa for the resolution 0.1 Pa. However, it could not be used because it was too sensitive and responded to any movement in and out of the chamber (digits jiggled on the digital display like crazy, which is why the last 5 digits were covered with adhesive tape to carry out the measurements). A separate problem is the difficulty of sampling to ensure a certain flow rate through the sensors of gas analysers, and to ensure the operation of the sanitary facilities, which only operate at a certain overpressure [4].

The tests covered the entire depth zone provided for nitrox (from 20 to 45 m). Below, there are examples of decompression tables for a system (which has never been used in practice) with a saturation plateau and oxygen partial pressure = 40 kPa. To meet the conditions specified in the tables, partial pressure of carbon dioxide had to be kept below 0.5 kPa at temperatures ranging between 25 and 27°C with conditions of harmful admixture contamination as defined in the ABS (American Bureau of Shipping – a classification organisation) document. The decompression time from a saturation plateau of 40 m was 83 h 25 min (or 3.5 days) while from 45 m it was 93 h 32 min, i.e., almost 4 days. For saturation plateau of 30 m, the decompression time exceeded 48 h. Those who worked out the course of decompression set high requirements, which were met in this case, but which then had to be observed by operational diving systems that did not have such technical and measurement capabilities.

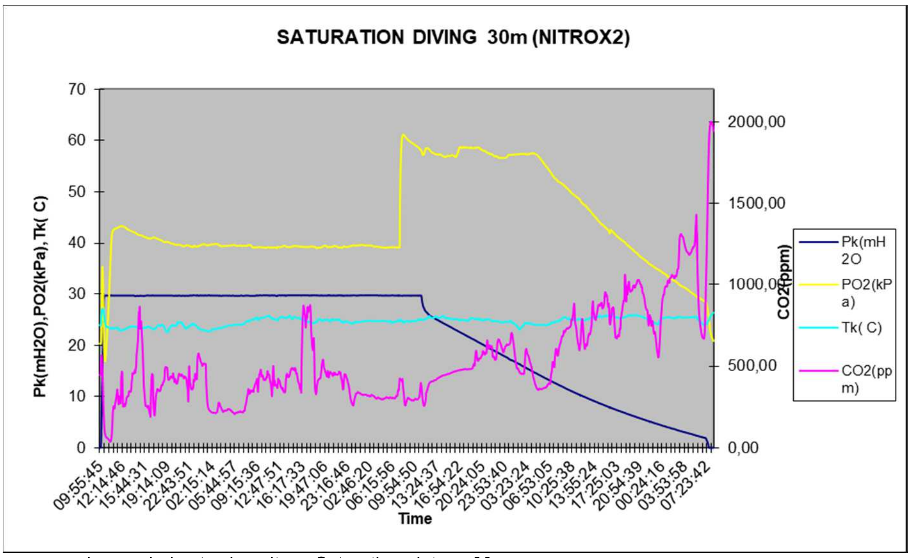

Fig. 2 Recorded course of decompression carried out using nitrox. Saturation plateau 30 m.

The recording shows the course of the entire experimental saturation exposure. The temperature pressure curves are stable. The compressed carbon dioxide waveform, on the other hand, shows how active the divers are in the chamber. The oxygen partial pressure waveforms show overshoots at the onset of isobaric decompression, i.e., an increase in oxygen partial pressure. This is the effect of unstable operation of the prototype electrochemical sensor, which occurred during phases of increased doses of oxygen due to its location in the chamber.

Tab. 2

Examples of nitrox decompression tables with saturation plateau 40 m of H_2O column for the depth from 40.0 m to 33 m [4].

No.	**Depth [m]**	**Stop time [min.]**	**Total time [hour]**
1	2	3	4
1	**40.0 – 39.0**	**5**	**0.5**
2	**39.0 – 38.0**	**11**	**0.16**
3	**38.0 – 37.0**	**16**	**0.32**
4	**37.0 – 36.0**	**22**	**0.54**
5	**36.0 – 35.5**	**32**	**1.26**
6	**35.5 – 35.0**	**61**	**2.27**
7	**35.0 – 34.5**	**61**	**3.28**
8	**34.5 – 34.0**	**61**	**4.29**
9	**34.0 – 33.5**	**61**	**5.30**
10	**33.5 – 33.0**	**61**	**6.31**

The nitrox saturation exposures tested the teams at technical and organisational levels, and prepared the medical team to approach problems associated with studies on saturation diving with trimix. On the medical side, decompression tests recorded no decompression incidents or changes in divers' health.

In constructing the decompression tables, Prof. Doboszynski and Dr Łokuciejwski took advantage of the very important role played by the physiological phenomenon known as the 'oxygen window.' As early as four hours before the decompression start time, isobaric decompression was used, increasing the oxygen partial pressure from 0.4 ata to 0.5 ata.

Tab. 3

Example of nitrox decompression with saturation plateau 40 m of H_2O column for the depth ranging between 15.0 m to 0 m [4].

No.	Decompression depth [m}‘	Time for reducing depth by 0.5m H_2O [mim]	Time from the start of decompression [hour:min]
47	15.0 – 14.5	64	44.24
48	14.5 – 14.0	64	45.28
49	14.0 – 13.5	64	46.32
50	13.5 – 13.0	64	47.36
51	13.0 – 12.5	64	48.40
52	12.5 – 12.0	64	49.44
53	12.0 – 11.5	64	50.48
54	11.5 – 11.0	66	51.54
55	11.0 – 10.5	68	53.2
56	10.5 – 10.0	69	54.11
57	10.0 – 9.5	71	55.22
58	9.5 – 9.0	73	56.35
59	9.0 – 8.5	75	57.50
60	8.5 – 8.0	78	59.8
61	8.0 – 7.5	80	60.28
62	7.5 – 7.0	83	61.51
63	7.0 – 6.5	85	63.16
64	6.5 – 6.0	88	64.44
65	6.0 – 5.5	91	66.15
66	5.5 –5.0	95	67.50
67	5.0 – 4.5	98	69.28
68	4.5 – 4.0	102	71.10
69	4.0 – 3.5	106	72.56
70	3.5 – 3.0	111	74.47
71	3.0 – 2.5	116	76.43
72	2.5 – 2.0	121	78.44
73	2.0 – 1.5	127	80.51
74	1.5 – 1.0	134	83.5
75	1.0 – 0.5	20	83.25

Oxygen partial pressure of 0.5 ata maintained until the oxygen content in the chamber reached 22% allowed for an increased oxygen window, as was the case for the decompression for short duration deep dives. This is called the extended oxygen window.

A characteristic sign of an expanded oxygen window is the shape of the profile in the first phase of decompression, in which the rate of depressurisation increases triggering a greater 'suction' gradient for nitrogen removal, which, in turn, accelerates nitrogen removal (see Figure 2 and Table 1). By way of simplification, this phenomenon contributes to the generation of a safe gradient of the nitrogen partial pressure differential in tissues and in the surroundings.

As evidenced by the absence of decompression incidents, medically, this method of decompression worked well in saturation exposures with nitrox. The safety margin of nitrox decompression is evidenced by the fact that one among the tester divers suffered from undetected *foramen ovale*, which was discovered a few years later during a decompression incident after short-duration dives at shallow depths.

The venous method of detecting bubbles in the blood was not used for decompression testing of divers for two reasons. Firstly, the measurement was considered unreliable and subjective. Secondly, there was a lack of funds to purchase a Doppler apparatus [4].

At that time, Dr Romuald Olszanski undertook the pioneering work aimed at detecting decompression risks based on other pathophysiological symptoms. In the decompression stage, divers can be exposed to the consequences of inert gas supersaturations. In a nutshell, these supersaturations may produce intravascular gas bubbles, acting as a foreign body. This, among other things, affects coagulation. Stimulation of the coagulation system activates thrombin, leading to platelet aggregation and release of platelet contents. Safety assessment of decompression tables and personal susceptibility to pressure sickness are mainly based on the detection of its pathophysiological symptoms. The study aimed to develop such diagnostic methods that would help to evaluate the decompression system. In the first phase, the investigation focused on the evaluation of platelet activation and selected elements of plasma haemostasis as an indicator of decompression sickness risk.

RESEARCH INTO TRIMIX MIXED DIVING 1987– 1994. RESEARCH FOR THE DEVELOPMENT OF A SAFE SATURATION DIVING SYSTEM IN THE 30- 120 M DEPTH RANGE

The safety requirements for saturation diving must be proportional to the complexity of the problem of prolonged human stay in a pressurised environment and offer the resilience necessary to cope with disturbances and emergency conditions. Saturation diving has the highest degree of risk and can be compared to space conditions. Saturation exposure is the ultimate procedure for therapeutic recompression. At the time, this procedure was only at the experimental research stage worldwide.

Results for saturation diving in the 30-120 m depth range were needed for [5]:

- carrying out remote tests at Polish manufacturers of diving systems for exports (four GWK -200 complexes with prospects for further deliveries).
- the establishment in Poland of a diving technology research base for medical and commercial research, with the parallel establishment of a hyperbaric rescue centre. Such a civilian centre was being organised at the Institute of Maritime and Tropical Medicine (Polish abbr. IMMiT) in Gdynia, however, with no staff.
- increasing the capacity of the Navy's underwater emergency-rescue potential, particularly for rescuing submarine crews.
- securing the provision of underwater works of the country's growing offshore oil and gas industry.
- From the 1980s onwards, the Navy's rescue vessels were the only ones with the technology for deep-sea diving using helium-oxygen mixtures. Semi-closed-circuit breathing apparatus was used based on data received from Drager company and the US Navy tables for such breathing equipment. For diving, a diving base with a deep-sea diving bell installed on Piast rescue ships was used. Dives carried out for defence and for the offshore industry were
- down to depths of 60-80 m, i.e., emergency dives with a diver's stay at the working depth for up to 30 min. [7]

When developing a saturation diving system at depths of 30-120 m, certain issues were identified that had to be resolved and tested in practice [6,7].

The system was expected to ensure:

- Maximum safety of the divers with regard to direct and subsequent indirect consequences.
- An increase in the diver's effective working time in the water to several hours, i.e., making it several times longer than in short dives.
- Comfortable physical and mental recovery conditions for divers between dives and proper regeneration.
- Testing the structural and technical domestic equipment and diving equipment of the DGKN-120, GWK-4200, LSH-200 units for 100 m as the depth required in approval tests for GWK-200 units (50% of the operational depths) [8].
- Work related to the use of the GAK 450 closed-circuit diving breathing equipment manufactured by Drager. This involved its ergonomic integration into the bell and infrastructure of the GWK-200 unit, as well as training of divers and operating personnel [8].

On the medical side, it was recognised that the development of a saturation diving system for heliox mixtures called for a new approach. From a physiological point of view, specific requirements had to be worked out to take the following into account:

- the physical characteristics, health status and training advancement of the divers,
- the composition of the breathing mixture and the comfort of staying under pressure,
- the method of compression and decompression from the saturation plateau,
- daily routine including workload, diet, rest (sleep) and recovery conditions of the divers,
- the research and medical support of the exposure, and subsequent verification of the components of the system during subsequent multi-day hyperbaric exposures in the DGKN-120 diving complex [3],
- drawing from own experience gained in research programmes focused on saturation diving using air and nitrox [9].

VALIDATION OF DEVELOPED DECOMPRESSION TABLES. A GENERAL SAFETY MODEL FOR DIVING

The method used for the validation of tables was based on the idea of increasing decompression loads by moving from lower to higher loads in successive exposures. In the first exposures, we used tables for a correspondingly lower oxygen partial pressure assumed at the saturation plateau. This procedure allowed a safety margin to be maintained, taking into account possible errors in the measurement of oxygen partial pressure. Systematic errors of gas analysis in determining the composition of the breathing mixture, its purification, inhomogeneity, inaccuracy of operators, and increased individual susceptibility to decompression stress were first considered in studies on divers participating in this type of exposure [10].

The course of validation of saturation dives was consistent with the research assumptions, the divers' daily schedules, and the decompression programmes subject to validation. By assumption, decompressions started after a 35 - 57 hour stay on the plateau. During the exposure, some parameters of the gas habitat deviated from the recommended values (the effect of these deviations on the course of decompression was taken into account in subsequent exposures):

- deviations from the partial pressure of oxygen were greater than required and were up to 3 - 5 kPa /± 6 - 10 %/,
- deviations from the desired temperature were greater than required and ranged from 2 - 3 ºC.

Other parameters or values were in accordance with the established requirements (P_{abs}, pCO_2, relative humidity, mixture movement, toxicological and microbiological contaminants).

RAISING THE PRESSURE IN THE HABITAT TO THE SATURATION PLATEAU [11]

Compression to plateau pressure was carried out in two stages. In stage one, divers are compressed with a starting mixture, the composition of which was selected to match the saturation level. The starting mixture was used up to the mid-depth of the plateau with protection by inhalers with an emergency mixture. In the second stage, in which the divers' participation was essential, the pressure was raised while the composition of the mixture in the chamber was stabilised. For example, for a saturation plateau of 100 m H_2O, the starting mixture was heliox with oxygen content of 3%. Compression to a depth of 50 m (600 kPa) is carried out at a rate of 2-4 m/min. During the compression, divers breathe an oxygen-helium mixture of 20% oxygen from their individual systems. Once the pressure equivalent to the depth of 50 m is reached, compression stops.

- Once it is decided that the partial pressure of oxygen in the chamber is higher than 20 kPa, the divers disconnect individually from their individual systems (at minute intervals) and switch to breathing the chamber atmosphere.
- Once all divers have switched to breathing the chamber atmosphere, further compression is initiated to a depth of 100 m, at the same rate as before, i.e., 2-4 m/min.
- From 50 m an oxygen-helium mixture of 6% oxygen content is connected to the individual breathing system.

ENVIRONMENTAL CONDITIONS REQUIRED AT THE SATURATION PLATEAU [11]

The conditions at saturation plateau depend on the pressure and the expected duration of the divers' stay and differ from those required during compression or decompression. During the divers' stay at the saturation plateau corresponding to the depth of 100 m using trimix as a breathing medium, the following ambient parameters should be maintained:

P_{abs} = 1100 kPa ± 1 ; $pO_2^{x/}$ = 40 kPa ± 2 $pN_2 \leq 80$ kPa ± 4 ; pHe ≈ 980 kPa $pCO_2 \leq 0.3$ % equivalent, temperature 30ºC ± 1; relative humidity 40-60 %, mixture movement ≤ 15 cm/sec; noise ≤ 70 dB/A/, short term 100 dB/A; microorganisms / up to 350 col/ m^3 in the absence of pathogenic flora. Volatile chemical compounds below $DNS^{x/}$.

$^{x/}$*In decompressed mixture.* [12]

DECOMPRESSION

For organizational reasons, the principles aimed at ensuring the technical support to decompression for saturation diving were included in the following research problems [13]:

1. decompression should be mapped as accurately as possible with a continuous pressure change at a specific rate expressed in m/hr and the obligatory maintenance of a constant partial pressure of oxygen while maintaining a specific thermal comfort and humidity in the chamber,
2. the continuity of decompression should not disturb the rhythm of divers' staying and living in the chamber. A particularly important problem was the fact that decompression continued while the divers were asleep. In this case, for the sake of safety, breathing and heartbeat of one of the divers were monitored, and during the night after 4 hours of sleep the divers' wellbeing was checked,
3. intervention procedures in cases of pressure sickness symptoms or other conditions. For these purposes, therapeutic mixtures and oxygen were prepared according to the depth, for the treatment procedures of a possible pressure sickness.

Three hours before decompression, the partial pressure of oxygen in the breathing mixture of the habitat should be increased from 40 kPa to 50 kPa.

1. At the start of decompression from a pressure corresponding to a depth of 100 m, the composition of the gas mixture should correspond to the following values: p O_2 = 50 kPa ± 2; $pN_2 \leq 80$ kPa ± 4; pHe ≈ 970 kPa.
2. From a depth of 100 m up to 14 m, the partial pressure of oxygen should be maintained consistently at 50 kPa.
3. Results of oxygen, nitrogen and helium control determinations should be reported in kPa, carbon dioxide in equivalent percentage.
4. From a depth of 14 m to the surface, oxygen content in the mixture should be given as a percentage and the concentration of this gas should be 22 % ± 0.8.
5. From a depth between 100 m and 50 m the individual breathing system should be supplied with an oxygen-helium mixture containing 6 % O_2.
6. From a depth of 50 m to the surface the individual breathing system should be supplied with an oxygen-helium mixture containing 20 % O_2. From a depth of 18 m to the surface it should also allow breathing pure oxygen.
7. During decompression the microclimate of the habitat should exhibit the above parameters of temperature, humidity and movement of the gas mixture (Table 1).

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